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ABSTRACTS OF CURRENT PUBLISHED INFORMATION ON NICKEL AND ITS ALLOYS

GENERAL

Zone Refining of Metals

J. H. WERNICK: 'Techniques and Results of Zone Refining Some Metals.'

Jnl. Electrochemical Soc., 1959, vol. 106, Mar., pp. 245–8.

The paper describes methods which have been used in the Bell Telephone Laboratories, for zone refining the metals shown below, in order to obtain material of specially high purity for research purposes. Apparatus is illustrated.

Metals refined:

(1) *Floating-zone refining*: Nickel, titanium, vanadium.

(2) *Boat-zone refining*: Aluminium, gold.

During floating-zone melting a considerable amount of purification was obtained by volatilization. Some typical analyses of the refined metals are given.

In the cases of nickel and gold the refined material was evaluated by measuring the residual resistances, at liquid-helium temperature, of sections of the zone-refined ingots. (The analysis of the high-purity nickel used as the starting material is detailed, but no analytical data on the zone-refined ingot are recorded.)

Production of Structural Parts by Powder Metallurgy: Design Factors

J. L. EVERHART: 'Designing for Metal-Powder Structural Parts.'

Materials in Design Engineering, 1959, vol. 49, Apr., pp. 113–24. *Manual No.* 158.

Components produced by powder-metallurgy techniques may be broadly divided into the following classes: (1) those having densities of the order of 50 per cent. of their theoretical densities (e.g., filters), (2) those with densities in the region of 75 per cent. (e.g., self-lubricated bearings), (3) those with densities in the range 80–95 per cent., and (4) those which have a density of virtually 100 per cent. Components falling within the last two groups are used mainly in structural applications, and it is solely with these that the present review is concerned. The author's aim is 'to help the engineer or designer to determine the properties of various powder mixtures, to help him select suitable designs to take full advantage of these properties, and to point out various applications that have been handled successfully'. Factors relevant in this respect are considered in five sections: some indication of the scope of the discussion is given below.

Properties of Metal-Powder Components

The review is based on tabular data indicating properties typical of metal-powder components fabricated from low-, medium- and high-density iron, copper-infiltrated iron, low-alloy nickel-containing steels, chromium and chromium-nickel stainless steels, copper, bronzes, brasses, nickel silvers, nickel, titanium and tungsten. The main applications of the non-ferrous materials are non-structural and the greater part of the section is therefore concerned with ferrous components, which, for discussion of properties, are subdivided into pressed-and-sintered parts, infiltrated parts and heat-treated parts.

Design of Components

The design considerations discussed relate to length/diameter ratios, bosses, draft angles, splines, knurls and serrations, chamfers or bevels, corner reliefs, longitudinal holes, and non-mouldable shapes. In discussing permissible tolerances, reference is made to a table listing those typical for ferrous and non-ferrous parts of uniform cross section.

Finishing Techniques

Short notes on plating and surface preparation of powder-produced parts.

Economic Factors

Economic production of components by powder-metallurgy techniques is discussed in terms of volume of production, size of component and rate of production.

Applications

The section is concerned with typical applications of low-, medium- and high-density iron components,

infiltrated iron parts, and copper, bronze and brass parts.

Diagrams and photographs illustrate the design features and applications considered in the review.

Spring Materials: Specifications and Design Factors

J. A. ROBERTS: 'Design and Specification of Springs.'
Engineering Materials and Design, 1959, vol. 2, Mar., pp. 140–3.

The article, which discusses the principles of spring design, and materials, is in three sections. In the first the author summarizes the factors governing the selection of the most suitable material for a particular spring: operational environment, class of duty to which the spring is to be subjected, and life requirement. The second section outlines the requirements of British specifications covering materials commonly used for springs, and is supplemented by a table listing the relevant specifications and the steels to which they relate. In the last section an outline is given of the formulae involved in spring design, and, in the same connexion, emphasis is placed on the importance of relating the maximum stress to which the spring is to be subjected to the material used. The article includes data on modulus of rigidity for 18–8 steel, 'Monel', 'Inconel' and 'Ni-Span C': permissible stresses are tabulated for the same materials and also for 'K Monel', 'Nimonic 90' and other alloys used in springs.

American Developments in Investment-Cast Materials

R. F. WAINDLE: 'Metal Specifications and Practices in the U.S.'
Foundry Trade Jnl., 1959, vol. 106, Apr. 9, pp. 409–14.

The article is an abridged version of a paper presented at the European Investment Casters' Congress held in Paris in 1958. The author's main aim was to indicate, particularly in relation to investment castings, the trends in development of high-temperature alloys and steels in America.

After reference to statistics showing the tendency towards higher production of steel investment castings, the requirements of U.S. specifications are critically reviewed and an outline is given of the types of material in current use in three fields. In high-temperature applications much more extensive use has been made of nickel- or cobalt-base castings for rotating components of gas turbines than in Europe. 'Intermediate-range' alloys are considered in relation to the chromium-nickel precipitation-hardenable semi-austenitic stainless steels developed to satisfy the structural requirements of the aircraft industry, and brief reference is made also to trends in low-alloy high-strength steels.

Future prospects of high-alloy castings in the U.S.A. are briefly considered, reference is made to vacuum-melting and-casting and, by way of exemplifying research on new alloys, a résumé is given of Freeman's findings with respect to the influence of boron and zirconium additions on the stress-rupture life and ductility of a nickel-chromium-cobalt-base alloy (see abstract in *Nickel Bulletin*, 1959, vol. 32, No. 1, pp. 16–17). In a final section attention is directed to factors which might be expected to offset existing prejudices against replacement of wrought materials by investment castings.

Physical Properties of Nickel and Nickel-containing Alloys and Steels

F. J. TEBO: 'Selected Values of the Physical Properties of Various Materials.'
U.S. Atomic Energy Commission, Report ANL-5914, Sept. 1958; 255 pp.

The report presents data, collated from the literature, on thermal conductivity, specific heat, density, viscosity and Prandtl numbers of solids, liquids and gases of interest in relation to nuclear-reactor heat-transfer and fluid-flow analysis. Where the data permit, the relevant values are given as a function of temperature; if the information available is insufficient for this purpose, values at room temperature are tabulated, where possible. A short list of references to additional data on physical properties is appended to the report.

Values for thermal conductivity, specific heat and density have been assembled for, *inter alia*, nickel, 'A' nickel, 'Inconel', 'Inconel X', 'Monel', 'K Monel', 'Nichrome V' and 18–8-type chromium-nickel stainless steels (A.I.S.I. Types 301, 303, 304, 310, 316, 321 and 347). Thermal-conductivity data are given for nickel oxide and a nickel-zirconium alloy containing 0·27 per cent. zirconium.

High-Temperature Testing: Recommended Procedures

AMER. SOC. TESTING MATERIALS: 'Tentative Recommended Practice for Short-Time Elevated-Temperature Tension Tests of Materials.'
A.S.T.M. Designation E 21–58*T*.
A.S.T.M. Standards, 1958, Pt. III, pp. 217–23.

This schedule, which covers procedure for determination of short-time tensile properties of materials above ambient temperatures, includes details of the test apparatus and specimens, also recommendations on methods of temperature-control and -measurement, and on strain measurement during test. A list is given of items relating to procedure and properties which should be given in a test report.

AMER. SOC. TESTING MATERIALS: 'Tentative Recommended Practice for Conducting Creep and Time-for-Rupture Tension Tests of Materials.'
A.S.T.M. Designation E 139–58*T*.
ibid., pp. 224–36.

The recommendations cover apparatus and procedure for determination of amount of deformation as a function of time (creep test) and measurement of time

time for fracture to occur when sufficient load is imposed (rupture test) materials under constant tension loads at constant temperature. The schedule also includes notes with regard to number and duration of tests, as a general guide to obtaining valid results, and recommendations are made on form of reporting.

Preparation of Metallographic Specimens

AMER. SOC. TESTING MATERIALS: 'Tentative Methods of Preparation of Metallographic Specimens.'
A.S.T.M. Designation E 3-58*T*.
A.S.T.M. Standards, 1958, Pt. III, pp. 556–621.

This schedule (comprising the first revision since 1946) presents, for the guidance of the metallographer, only practices which experience has shown to be satisfactory. To simplify presentation of the reference information, those phases of the preparation of metallographic specimens which vary little with the material are discussed collectively, while special features particularly applicable to one metal and its alloys are presented in separate sections relating to the respective materials. Electropolishing solutions are listed, with details of technique for treatment of the individual materials, and compositions of etching solutions and procedure are also tabulated. The schedule is supported by an extensive *bibliography*.

Testing of Hot-Cracking Susceptibility of Welds

See abstract on p. 205.

NICKEL

Refining of Nickel from American Ores

W. R. MCCORMICK: 'Production of Cobalt, Nickel and Copper at the Fredericktown Metals Refinery.'
Paper presented at *Mid-America Minerals Conference, Amer. Inst. Mining and Metallurgical Engineers*, Oct. 1958; 17 pp.

The paper describes, with many photographs and a flow sheet, the plant and process used by National Lead Company for refining of cobalt, nickel and copper from the concentrates obtained from the sulphide ore in Madison County, Missouri. The Fredericktown Refinery is now the only commercial producer of primary nickel in the U.S.A. and is the country's second largest producer of cobalt.

Zone Refining of Metals

See abstract on p. 169.

Physical Properties of Nickel

See abstract on p. 170.

Influence of Trace Elements on Properties of High-Purity Nickel

K. M. OLSEN: 'The Effect of Trace Elements on the Tensile, Electrical Resistance and Recrystallization Properties of High-Purity Nickel.'
Trans. Amer. Soc. Metals, 1958, vol. 52, *Preprint* 130; 16 pp.+ tables and figures.

The study reported in this paper is part of a comprehensive investigation in progress at the Bell Telephone Laboratories, designed to determine the influence of minor constituents on the emission characteristics and life of oxide-coated nickel cathode structures used in vacuum tubes such as those employed as repeaters in transoceanic cables. Whereas earlier published reports on the effects of small amounts of other elements on high-purity nickel relate mainly to studies on metal processed directly from special electrolytic strip or from sintered powder, the basis material used in the investigation described in the present paper was prepared by melting and casting in a controlled atmosphere. (No deoxidizers were used.) The metal was of such purity that the few hundredths of one per cent. of elements intentionally added constituted 'major' constituents. Chemical analyses show that no single impurity was found in amounts exceeding 0·005 per cent. by weight, and this degree of purity was maintained for all the materials containing the elements intentionally added. (The methods used in preparation of the basis metal were described in *Metal Progress*, 1957, vol. 71, Sept., pp. 105–9; *Nickel Bulletin*, 1958, vol. 31, No. 1, p. 2.)

The effects of the following elements, in trace amounts, were determined: magnesium, aluminium, manganese, silicon, boron, carbon, zirconium, cobalt, tungsten and titanium. The properties studied were electrical resistance, tensile strength and recrystallization characteristics. The measurements were made on 0·025-in. (0·625-mm.) diameter wire.

It is concluded that the results obtained on 'nickel' containing elements which are likely to form solid solutions are related mainly to degree of lattice distortion which the addition elements produce. In the case of elements having very limited solubility in nickel an additional factor is the nature and degree of dispersion of the second phase present. Within the limits of this investigation, the data indicate that the greater the increase in atomic diameter of the added element in relation to that of nickel, the higher is the recrystallization temperature. The greatest rise resulted from addition of the largest atoms, magnesium and zirconium: the most pronounced retardation of recrystallization was produced by addition of 0·1 per cent. by weight of zirconium, which caused approximately 400C°. rise in recrystallization temperature over that of pure nickel.

On an atomic per cent. basis, additions of tungsten, titanium and silicon had the greatest effect in increasing the resistivity of nickel. Zirconium and carbon exerted the greatest effect in raising tensile strength.

Internal Ferromagnetic Resonance in Nickel

J. C. ANDERSON and B. DONOVAN: 'Internal Ferromagnetic Resonance in Nickel.'

Proc. Physical Soc., 1959, vol. 73, Apr. 1, pp. 593-9.

The work described was a continuation of earlier investigations in which the materials used had been a series of iron-nickel alloys (*ibid.*, *B*, 1957, vol. 70, p. 186). The present paper reports an investigation of internal resonance in nickel, as revealed by measurements of complex permeability, over the temperature range 5°-100°C. The resonant frequency is found to be a decreasing function of temperature: over the range studied the variation is approximately from 450 to 300 Mc/s in the case of a polycrystalline disc, and from 270 to 40 Mc/s for a colloidal suspension of nickel particles. These findings are consistent with the view that the resonance is due to the internal magnetic field associated with the anisotropy energy. The authors propose a quantitative interpretation, using the available experimental values for the anisotropy constants.

Colorimetric Determination of Nickel

B. DASSARMO and K. R. RAY: 'New Method for the Colorimetric Estimation of Nickel.'

Science and Culture, 1958, vol. 23, pp. 565-6.

The procedure described, which provides for determination of trace amounts of nickel and precludes any colour intensification of the nickel, consists in decomposing the sample by acid digestion or pyrosulphate fusion, filtering, complexing iron and aluminium with citrate or tartrate, rendering alkaline with ammonia, and extracting with amyl alcohol in a separatory funnel. The aqueous layer is drawn off and the organic layer is washed with dilute ammonia. The organic extract is shaken with 2 cc. of 0·5 per cent. dimethylglyoxime in amyl alcohol to which 4 cc. of sodium hydroxide is added for every 10-15γ of nickel present. The colour in the lower aqueous phase is then compared with standards extracted in the same way.

Determination of Nickel in Gold-Nickel Alloys

D. H. WILKINS and L. E. HIBBS: 'Determination of Nickel in Gold-Nickel Alloys.'

Analytica Chimica Acta, 1959, vol. 20, Mar., pp. 273-4.

Determination of nickel in gold-nickel alloys is complicated by the fact that the dioximes usually employed for precipitation of nickel will reduce gold to the metal. In order to avoid a sulphide precipitation for the separation of gold, a study was made of the possibility of using anion exchange as a rapid means of separation. Previous work has indicated that gold chloro complexes are strongly adsorbed from a hydrochloric-acid solution on a strongly basic anion-exchange resin, whereas nickel exhibits no adsorption in chloride solutions. This paper describes a method based on that difference, combined with final determination of nickel by back titration of an excess of standard EDTA with a standard copper solution.

Determination of Nickel, Zinc and Aluminium in Bronze

See abstract on p. 180.

Determination of Nickel in Ferrites

See abstract on p. 182.

Removal of Zinc from Ammoniacal Nickel Solution

L. BLOCH: 'Thioacetamide, a New Reagent for Removal of Zinc from an Ammoniacal Nickel Solution.'

Chemisch Weekblad, 1958, vol. 54, pp. 384-6.

The paper describes a method for separation of zinc from a solution containing nickel, by precipitation with thioacetamide (T.A.A.) in ammoniacal medium. The author refers to earlier literature recording the use of this reagent in place of hydrogen sulphide, and points out that its application in the manner described in the paper is a further confirmation of the possibility of using T.A.A. in place of H_2S in quantitative and qualitative analysis.

Preparation of Metallographic Specimens

See abstract on p. 171.

Fabrication and Design of Nickel Pipe and Tube

See abstract on p. 181.

New French Coinage

H. G. CORDERO: 'Jottings in Transit.'

Metal Bulletin, 1959, No. 4380, Mar. 20, pp. 13-14.

In the course of this brief survey of the economic situation in France and Germany the author alludes to the new French 'heavy' currency which is to be introduced in the near future. The coinage and metals used are listed in the table below.

Coin	Metal
1 and 2 centime	Aluminium alloy
5, 10 and 25 centime	Aluminium bronze
50 centime	Cupro-nickel
1 franc	Nickel
2 and 5 franc	Silver 838/1000 pure

Machining of Nickel

See abstract on p. 181.

Nickel Electrodes in Fuel Cells

E. GORIN and H. L. RECHT: 'Fuel Cells.'
Blast Furnace and Steel Plant, 1959, vol. 47, Feb., pp. 206–9.
Reprint of paper presented to American Society of Mechanical Engineers, Nov.–Dec. 1958.

The nature of fuel cells and the significance of such cells in the power industry are briefly discussed, as an introduction to a description of the design and characteristics of the two basic types of cell: (1) the low- and medium-temperature type, of which the most representative model is that developed by F. T. Bacon (*Beama Jnl.*, 1954, vol. 61, pp. 6-12; *see also* following abstract), and (2) the high-temperature cell, on which extensive work has been carried out in Holland, by Ketelaar.

The main part of the paper is devoted to a description of a high-temperature fuel cell developed by Consolidation Coal Company, U.S.A., which is closely similar in principle to the design developed in Holland. The operation of the unit is described, and the potential usefulness of fuel cells as a means of permitting coal to remain competitive with nuclear power is emphasized.

In both the medium-temperature and high-temperature cells to which reference is made, nickel is used as fuel electrode.

F. T. BACON: 'The Hydrogen-Oxygen Fuel Cell.'
N.R.D.C. Bull.*, 1959, No. 14, Apr., pp. 29–32.

The author gives an account of progress made to date on the hydrogen-oxygen fuel cell, discussing, in particular, recent work concerned with the development of a battery capable of producing useful amounts of power, a project which is being sponsored by the National Research Development Corporation.

A 10-in cell which has been in operation since March 1958 has given roughly four times the current obtainable with the 5-inch-diameter cell used during the earlier phases of the work. To date, up to ten cells in series have been operated, and no special difficulties have been encountered with, for example, sealing of the joints, excessive shunt current between cells, excessive electrolysis in electrolyte ports. Troubles associated with the manufacture of the large-diameter electrodes, which are sintered directly onto a flat circular perforated sheet of nickel or nickel-plated steel, have diminished as more experience was obtained. The article includes notes on control of gas admission, removal of water, and removal of gas from the condensate system. Work envisaged in the future is outlined, with emphasis on the importance of fuel-cell development in the U.K.

*National Research Development Corporation.

Nickel Catalysts in Syntheses of Acetic and Propionic Acids

S. K. BHATTACHARYYA and S. SOURIRAJAN: 'High-Pressure Syntheses of Acetic and Propionic Acids from Alcohols and Carbon Monoxide in Presence of Nickel, Cobalt and Iron Catalysts.'
Jnl. Applied Chemistry, 1959, vol. 9, Pt. II, Feb., pp. 126–33.

The results of previous investigations by the authors had shown that high yields of acetic acid could be obtained by synthesis from methanol and carbon monoxide if the reaction was carried out, in the presence of a nickel-iodide/silica-gel catalyst at 200°C. and in the vapour phase, at pressures ranging from 3000 to 4000 p.s.i. (2·1–2·8 kg./mm.²): *ibid.*, 1956, vol. 6, p. 442. The work now reported represents an extension of this research, to cover synthesis of acetic acid in the presence of cobalt or iron catalysts and the corresponding synthesis of propionic acid from ethanol and carbon monoxide in the presence of nickel, cobalt or iron catalysts.

Two types of catalyst were selected for study: metal/silica, incorporating, as the metal, nickel, cobalt or iron; halide/silica, containing iodides, bromides or chlorides of nickel, cobalt or iron. The activity of the catalysts, and the effect of the following variables, are discussed: temperature, pressure, catalyst concentration, 'residence period', 'low-temperature release', presence of water and steam.

The data obtained showed that reduced metallic catalysts produced extremely poor yields of acid. The halides were, however, found to be active catalysts, their potency decreasing in the order nickel, cobalt, iron, and iodide, bromide, chloride.

Optimum yields of acids and esters were obtained with the nickel-iodide catalyst, using an equal weight of silica as support, a temperature of about 230°C., a pressure of about 3000 p.s.i. (2·1 kg./mm.²) and a 'residence time' of approximately 2 hours. The presence of about 5 per cent. of water in the alcohol was beneficial, and increased yields are achieved by cooling the bomb to about 60°C. before release of gaseous pressure. The catalyst is reactivated after use by addition of 0·5 ml. of water per 10 g. of catalyst. Decomposition of the alcohols and acids to gaseous products (carbon monoxide, hydrogen and saturated lower paraffins) is discussed.

Nickel Chloride for Treatment of Wheat Rust

'Anti-Rust Wheat Chemical.'
Chemical Processing, 1958, Dec., p. 93.

At the 1958 Convention of the Canadian Agricultural Chemical Association it was reported by Dr. Sackston, of the Plant Pathology Section of the Federal Department of Agriculture Research Laboratory in Winnipeg, that not only complex salts of nickel, but also the simple inorganic salts, will stop development of rust in an affected wheat field. A solution mentioned contains one pound of nickel chloride to 10 gallons of water. See also related reference in *Family Herald*, 1959, Jan. 8, p. 6.

ELECTRODEPOSITION AND OTHER COATING METHODS

Handbook on Nickel Plating

INTERNATIONAL NICKEL CO., INC.: 'Practical Nickel Plating.'

Second Edn., published 1959; 55 pp.

The booklet, which is intended 'primarily for the benefit of the reader who is unfamiliar with the many factors involved in coating materials with nickel', forms a ready means of reference to fundamental information on the various nickel-plating processes. It has been prepared, in particular, with the aim of indicating the suitability of the respective processes for producing deposits for given applications. The subject matter of the first edition was limited to electrodeposition of nickel, and information on this subject, amended and supplemented where required, comprises the greater part of the second edition, but the scope of the handbook has now been extended to include electroless nickel-plating.

Emphasis is laid on the practical aspects of nickel plating, which are dealt with in chapters relating to: applications of nickel plating; plating solutions, operating conditions and properties of deposits; preparation of basis metals for electroplating; special precautions for thick deposits; plating difficulties and their correction; purification of solutions; effect of elevated temperatures on nickel deposits; stop-offs and rack coatings; machining and grinding nickel deposits; stripping nickel and chromium deposits; nickel anodes; materials of construction for plating plant; nickel plating by non-electrolytic processes.

The handbook includes tables showing corrosion rates of various alloys in nickel-plating solutions of different types, deposition rates for nickel and chromium, physical constants of commercially pure electrodeposited metals, factors useful in nickel-plating calculations, and conversion factors. A selected *bibliography* of 53 items is appended.

Nickel/Chromium Coatings: Dutch Specification

HOOFDCOMMISSIE VOOR DE NORMALISATIE IN NEDERLAND: 'Electroplated Coatings of Nickel and Chromium.'

NEN 329, issued Oct. 1958; 2 pp.

This standard relates specifically to nickel coatings, with an overlayer of chromium, electrodeposited onto low-alloy or carbon steel, copper, or alloys with a copper content of at least 50 per cent. Where the basis metal is steel, the presence or absence of an initial layer of copper must be expressly agreed on between supplier and purchaser. The cobalt content of the nickel must not exceed 25 per cent. The chromium coating must be at least 0·25 μm. thick.

The schedule lays down specific and general requirements with respect to the composition, thickness, adhesion, porosity, appearance and marking of coatings, and refers to standards covering procedures to be used in determining thickness and porosity. Four classes of coating are considered. These classifications are defined, and thickness and porosity requirements are summarized in the table p. 175.

Co-Deposition of Nickel and Hydrogen from Aqueous Plating Solutions

J. YEAGER, J. P. CELS, E. YEAGER and F. HOVORKA: 'The Electrochemistry of Nickel. I. Co-deposition of Nickel and Hydrogen from Simple Aqueous Solutions.'

Jnl. Electrochemical Soc., 1959, vol. 106, Apr., pp. 328–36.

Electrodeposition of nickel has been studied extensively in relation to the structural characteristics of the deposits, or by polarization or efficiency measurements, but the plating solutions used have generally contained appreciable concentrations of two or more anions and often various addition agents. The relative complexity of these systems renders them unsuitable for use in fundamental research on the plating parameters involved.

The work described in the present paper was concerned with simple aqueous solutions which contained only one type of anion at a time (either the sulphate or the chloride). Cathodic polarization and current efficiency were measured during plating as a function of nickel-ion concentration, pH, and temperature, and the data obtained were employed to calculate, as a function of current density, the activation polarization for electrodeposition of both nickel and hydrogen. The structure of the deposits was examined by X-ray-diffraction techniques.

REISER and FISCHER (*Zeitsch. für Elektrochemie*, 1954, vol. 58, p. 668) concluded from their investigations of simultaneous deposition of hydrogen and nickel that the two deposition processes are interdependent during co-deposition on a nickel surface; one objective of the authors' investigation was to examine further the relationship between the polarization curves for nickel and hydrogen during simultaneous discharge; in particular, as affected by nickel- and hydrogen-ion activities in the chloride and sulphate solutions employed.

Experimental procedure is described and the data obtained are presented in detail.

At relatively high current densities the deposits showed a slight tendency to two preferred orientations. Small variations in grain size were observed, but these could not be correlated with current density. Grain size was usually smaller in deposits made from sulphate solutions than in those produced from chloride electrolytes. Polarization associated with electrodeposition of nickel was found to be substantially independent of pH and of the type of anion present at constant nickel-ion activity, and to follow the Tafel-type dependence on current density, with a Tafel slope of 0·10. The nickel-polarization data are considered to be explicable in terms of the transfer of a nickel ion from the

Requirements for Nickel Electrodeposits: Dutch Specification NEN 329

(*See abstract on p. 174*)

Class	Service Conditions	Minimum Thickness of Coating				Porosity of Coatings on Steel*
		On Steel			On Copper or Copper Alloys	Maximum Average Number of Pores per dm.²
		Without Copper Underlayer	With Copper Underlayer			
			Total	Minimum Nickel		
A	Indoors, in applications not involving exposure to dampness or wear	10 μm.	10 μm.	5 μm.	3 μm.	No maximum specified
B	Indoors and subjected to wear or to dampness; out of doors but not subjected to wear or to exposure to *all* types of atmospheric conditions	20 μm.	20 μm.	10 μm.	6 μm.	30
C	Subjected to atmospheric exposure, to wear, or to corrosion from running or condensed water	30 μm.	30 μm.	20 μm.	12 μm.	10
D	Subjected simultaneously to atmospheric exposure and to wear	50 μm.	50 μm.	40 μm.	24 μm.	3

* No maximum is laid down for the number of pores in coatings on copper or copper alloys.

solution across an unsymmetrical potential energy barrier to the metal phase. Hydrogen overvoltage, as evaluated during co-deposition at constant pH, was virtually the same (with a Tafel slope of 0·12) for both chloride and sulphate solutions, and, under the range of plating conditions studied, deposition of hydrogen and nickel appeared to proceed without any significant interdependence.

Electrodeposition of Nickel on Group IV, V and VI Metals

E. B. SAUBESTRE: 'Electroplating on Certain Transition Metals (Groups IV, V and VI).'

Jnl. Electrochemical Soc., 1959, vol. 106, Apr., pp. 305–9.

Conventional techniques for plating the transition metals of groups IV, V and VI involve (1) activation of the surface by etching in a suitable acid, (2) deposition of a thin film of nickel or iron, (3) baking to remove adsorbed gases, and (4) final heat-treatment to improve adhesion of the electrodeposited coating. The activation stage is usually effected by immersion treatments or anodic etching: cathodic treatment has been avoided because of the tendency to hydride formation or occlusion of hydrogen during etching. The author of this paper found, during a study of procedures used to coat transition metals of the three groups, that although immersion- and anodic-etching both resulted, in general, in reasonably satisfactory coatings, some difficulties were encountered, usually due to peeling of the as-deposited coating and blistering during the baking stage. On the assumption that the failures were due to excessive occlusion of gases prior to plating, a preliminary vacuum bake was carried out before the plating stage, but adhesion deteriorated markedly, a result which suggested that satisfactory adhesion might somehow be favoured by the presence of gas occluded during etching. Experiments were therefore carried out to determine the effect of substituting, for the conventional etch, cathodic treatment in an electrolyte which does not attack the substrate. The results of the investigation are recorded in this paper.

It was found that deliberate evolution of hydrogen on the substrate surface did indeed markedly improve adhesion of the deposit in the as-plated condition. The cathodic treatment, which probably results in

formation of surface hydrides, may be carried out in any electrolyte not containing ions of platable metals (e.g., in dilute mineral acid or alkali metal hydroxide solutions). The following sequence was used to obtain adherent nickel and copper deposits (0·2–0·3 mils thick) on titanium, zirconium, niobium, tantalum, molybdenum and tungsten.

'1. Soak in alkaline cleaning solution at 180–200°F. (82°–93°C.).

'2. Rinse.

'3. Etch in 10 per cent. (wt.) HF (*see* Note 1). *Immersion*—Ti, Zr, Hf. *Anodic* at 50 a.s.f. (5·4 amp./dm.^{2})—V, Nb, Ta, Mo, W.

'4. Rinse.

'5. Cathodic for 5–15 sec. at 10–100 a.s.f. (1·08–10·8 amp./dm.^{2}); room temperature; electrolyte, *see* Note 2.

'6. Rinse.

'7. Nickel plate for 30 sec.–2 min.: $NiSO_4.6H_2O$, 300 g/l; $NiCl_2.6H_2O$, 37·5 g/l; H_3BO_3, 37·5 g/l; 65°C.; 5–100 a.s.f. (0·54–10·8 amp./dm.^{2}); pH=4.

'8. Rinse.

'9. Plate as desired.

'*Note* 1. Step 3 is optional, and is needed only if it is desired to remove the surface and prepare a new, clean one.

'*Note* 2. Suitable electrolytes are 2 per cent. (wt.) HCl, H_2SO_4, HNO_3, HF, KOH, NaOH. The anode should be inert; platinum was used in the laboratory study.

'If the part which has been plated is to be subjected to high temperatures during use the hydrogen present under the deposit (in any form) will cause blistering, and lifting of the deposit may result. For such applications, the following procedure is used:

'1–8. As above.

'9. Dry.

'10. Vacuum fire at 450°–750°C. until gas ceases to be evolved.

'11. Nickel strike (Wood's nickel), then plate as desired.

'In either of the above procedures, iron plating may be substituted for nickel plating in step 7.

'In the above procedure the acid-etching step may be omitted to ensure that no dimensional changes occur in the substrate.'

In an effort to eliminate also any heat-treatment, investigations were made of an anodizing procedure suitable for pre-treatment of niobium and a 75-25 niobium-titanium alloy. The procedure finally developed (which was successfully used to plate the two materials with nickel and iron) is described below.

'1. Soak in alkaline cleaning solution at 90°C. for 2 min. Any strong ferrous electrocleaner may be employed satisfactorily.

'2. Rinse.

'3. Anodic in 10 per cent. (wt.) NaOH solution at about 5 v. at room temperature, to produce yellow (straw-coloured) film on the substrate. (Any metal not attacked by NaOH may be used as cathode.)

'4. Rinse.

'5. Coat with nickel or iron: $NiCl_2.6H_2O$, 220 g/l; HCl (sp. gr. 1·18), 125 ml/l; 25°C.; 30 a.s.f. (3·24 amp./dm.^{2}). When visibly covered with nickel, rinse and plate; $NiSO_4.6H_2O$, 300 g/l; $NiCl_2.6H_2O$, 37·5 g/l; H_3BO_3, 37·5 g/l; 65°C.; 5–10 a.s.f. (0·54–1·08 amp./dm.^{2}); pH=4.

Or, if iron is desired: $FeSO_4.7H_2O$. 300 g/l; $FeCl_2.4H_2O$, 40 g/l; $(NH_4)_2SO_4$, 15 g/l; 60°C.; 10–20 a.s.f. (1·08–2·16 amp./dm.^{2}); pH=4.

'6. Rinse.

'7. Dry.

'8. Heat to red heat in air, or in vacuum for about 2 min.

'In the anodizing treatment, the colour of the anodized film is critical; the other conditions are not. For example, the NaOH may be as dilute as desired, consistent with rendering the solution conductive: it may be as concentrated as desired, up to the limit of solubility. Temperature of the solution may lie anywhere between freezing and boiling. Formation of an improper film may be detected readily by visual means, by observing the colour, as follows: (*a*) colourless—too thin, (*b*) yellowish-brown—slightly too thick, and (*c*) blue or purple—much too thick.

'In general, increased film thickness is favoured by lower temperatures, higher solute concentration, and higher voltage.'

The cleaning and anodizing stages may be combined by using P.R. (periodic reversal of current) during cleaning. The treatment cycle is then as follows:—

'1. P.R. treatment in a strong alkaline electrocleaning solution at 90°C. at about 5 v., with a cycle of 8 sec. anodic and 4 sec. cathodic; treatment time 2 min.

'2. As in steps 4–8 above.'

Electrodeposition of Nickel-Iron and Nickel-Cobalt Alloys from Pyrophosphate Solutions

V. SREE and T. L. R. CHAR: 'Electrodeposition of Nickel-Iron and Nickel-Cobalt Alloys from the Pyrophosphate Bath.'
Bull. India Section, Electrochemical Soc., 1958, vol. 7, No. 3, pp. 72–5.

The paper is one of a series describing experiments carried out to study the electrodeposition of various metals and alloys from pyrophosphate solutions (see, for example, references to previous papers by CHAR in *Nickel Bulletin*, 1958, vol. 31). In the phase of the investigation now described the authors were concerned with the establishment of optimum

plating conditions for electrodeposition of nickel-iron and nickel-cobalt alloys. Findings are summarized in *Chemical Abstracts*, 1959, vol. 53, Feb. 25, p. 2876.

Radioisotopic Study of Levelling in Bright-Nickel-Plating Solutions

S. E. BEACOM and B. J. RILEY: 'A Radioisotopic Study of Levelling in Bright-Nickel-Plating Solutions.'
Jnl. Electrochemical Soc., 1959, vol. 106, Apr., pp. 309–14.

The mechanism involved in the levelling which occurs during electrodeposition of bright nickel has been the subject of much investigation, and findings in this respect have proved conflicting. General agreement exists, however, that levelling is accompanied by an increase in polarization. Some theories assume that an organic addition agent which promotes levelling is adsorbed or co-deposited on the peaks of an irregular surface, resulting in localized polarization which partially inhibits deposition of metal at the peaks and diverts current flow to recessed areas. The purpose of the work described was twofold: (1) to determine if an organic agent known to promote levelling is co-deposited or adsorbed preferentially on the peaks of the basis metal, (2) to develop radio-tracer techniques suitable for establishing the location, within electrodeposits, of a radioactive organic addition agent.

In the investigation the brighteners sodium allyl sulphonate and N-allyl quinaldinium bromide were added to a Watts solution, to promote levelling and to give laminated deposits. (It was thought that an adequate explanation of levelling must necessarily be compatible with occurrence of lamination formation.) During synthesis, the sodium allyl sulphonate was rendered radioactive by inclusion of the isotope S-35. Plating conditions are described and an outline is given of the counting procedures and autoradiography used to determine the distribution of the radioactivity over the surface of the nickel foil formed by removal of the deposit from the cathode block.

Autoradiograms and counting data show that the radioactive addition agent or its reduction products are indeed preferentially adsorbed or co-deposited on the peaks of the surface. (The present results show only that the S-35 atom is located in the deposit: no attempt was made to determine whether the agent was present as the sulphonate or as its reduction product, sulphide ion.)

With the type of plating solution used by the authors the levelling process is accompanied by the formation of laminations associated with 'dark' bands. The data obtained suggest that the presence of laminations is also explicable in terms of preferential adsorption of the addition agent, i.e., as the result of a cyclic process involving deposition of alternate layers of metal and of the leveller or its reduction product.

Corrosion-Resistance of Automobile Components

See abstract on p. 197.

Determination of Sulphur in Nickel Electrodeposits

V. K. BUKINA, A. L. SHUL'TS and N. I. KONONENKO: 'The Determination of Sulphur in a Nickel Electrodeposit by a Microanalytic Method.'
Doklady Akad. Nauk Uzbek. S.S.R., 1958, No. 6, pp. 27–9.

Determinations of sulphur occluded viâ organic additives present in the electrolyte were made on nickel coatings deposited from solutions containing hyposulphite, thiourea, and potassium thiocyanate. The coatings were removed from the basis metal (Armco iron sheet) and ground to a fine powder, 5–8 mg. of which were heated for 35–40 minutes in hydrogen in the presence of platinum as a catalyst. The resulting H_2S was absorbed in a 2 per cent. Cd $(OAc)_2$ solution acidified with AcOH. After addition of a volume of 6–8 ml. of $0{\cdot}02N$ iodine solution, the solution was back-titrated with $0{\cdot}02N$ hyposulphite in the presence of starch. The results showed good agreement with those obtained by gravimetric analyses with $BaSO_4$. Sulphur contents were in the range 1·4–4·24 per cent.

Measurement of Thickness of Electrodeposited Coatings

AMER. SOC. TESTING MATERIALS: 'Standard Methods of Test for Local Thickness of Electrodeposited Coatings.'
A.S.T.M. Designation A 219–58.
A.S.T.M. Standards, 1958, Pt. III, pp. 322–8.

This standard, prepared under the joint aegis of the American Electroplaters' Society, the National Bureau of Standards and the American Society for Testing Materials, covers procedures for measuring local thickness of electrodeposited coatings of copper, nickel, chromium, lead, zinc or cadmium, by microscopic and other tests, and for determination of local thickness of chromium coatings by a hydrochloric-acid spot test.

NON-FERROUS ALLOYS

Wrought Cupro-Nickels: Data Sheet

'Wrought Cupro-Nickels: A Materials Data Sheet.'
Materials in Design Engineering, 1959, vol. 49, Apr., p. 127.

The data sheet covers compositions, and physical and mechanical properties of cupro-nickels containing 10, 20 and 30 per cent. of nickel. Hot-working and annealing temperatures are given, and machinability, cold- and hot-workability, corrosion-resistance, and soldering, brazing and welding characteristics are assessed. Reference is made also to forms in which the materials are available and the purposes for which they are used.

Specific Heats of Copper-Nickel Alloys at Sub-Zero Temperatures

G. L. GUTHRIE, S. A. FRIEDBERG and J. E. GOLDMAN: 'Specific Heats of Some Copper-Rich Copper-Nickel Alloys at Liquid-Helium Temperatures.'

Physical Rev., 1959, vol. 113, Jan. 1, pp. 45–8.

Report of measurements on alloys containing 60, 65, 75 and 90 per cent. by weight of copper. The results are in approximate agreement with those reported by KEESOM and KURRELMEYER (*Physica*, 1940, vol. 7, p. 1003). The higher-copper alloys of the groups examined were found to obey a law of the type $c_v=\gamma T+\beta T^3$, but anomalies were noted in the behaviour of some of the 65 and 60 per cent. copper alloys. These are attributed to a magnetic effect, the significance of which is discussed. Analysis of the results shows that the usual collective-electron interpretation of the intrinsic magnetization of copper-nickel alloys is over-simplified.

Non-Ferrous Alloys in Marine Engineering in the U.S.A.

F. HUDSON: 'Marine and Power Engineers Meet in the United States.'

Foundry Trade Jnl., 1959, vol. 106, Apr. 30, pp. 495–504.

The First International Meeting of Marine and Power Engineers and the Fifth Annual Meeting of Naval Architects and Small-Boat Builders were held in the U.S.A. in 1958. In this article the author, who took part in both meetings, discusses items of interest from the papers presented.

The meeting of the Marine and Power Engineers was preceded by a series of visits, one of which was to the Harbor Island and Kure Beach corrosion-testing stations of The International Nickel Company. Some of the facilities at both stations are described.

Reference to papers at the technical meetings is made mainly on the basis of their interest in relation to non-ferrous castings used in the marine and power fields: in particular, high-tensile nickel-aluminium bronzes are discussed. Points selected for comment include the mechanism of erosion damage, the microstructure of aluminium bronzes, and methods of repair of propellers of that material. In connexion with propeller production and use, some data on the properties of typical nickel-aluminium bronze are given. The use of this material is steadily increasing in the U.S.A. and Canada, and propellers of this type have already been fitted to a large number of naval and merchant vessels, including the nuclear-powered submarines 'Nautilus' and 'Sea Wolf'.

In reviewing some other points of general interest in relation to the use of cast non-ferrous materials in marine engineering, the author alludes to the excellent service life of 90-10 cupro-nickel tubes in marine and power installations, experience of which has led to development of casting alloys of broadly similar types. Particular attention is directed to two 12 per cent. nickel casting alloys (containing, respectively, manganese 1, iron 1·2, per cent., and aluminium 1·5, manganese 1, iron 0·6, per cent.).

Other items of interest mentioned as being noted in the U.S. non-ferrous foundries include the successful use of 'Petro-bond', a new sand binder consisting of a clay which has been treated in such a way as to develop its bond with a petroleum-base oil rather than with water.

The meeting of Naval Architects and Small-Boat Builders is reviewed in short sections dealing with die casting of non-ferrous parts for large outboard motors, and improved materials (high-tensile aluminium bronzes) for propellers for such craft, some of which achieve speeds of up to 50 m.p.h. In this connexion reference is made to work done in the U.K., in 1940, on cast aluminium-containing 'Monel' and nickel-titanium-aluminium alloys, both of which materials have mechanical properties superior to those of high-tensile aluminium bronze, combined with outstandingly good resistance to corrosion and erosion by sea water.

In conclusion, the writer draws attention to the advantages, for marine service, of 'Monel' castings, as exemplified by a large propeller which, after 40 years' service, was found to be completely free from corrosion.

Physical Properties of Nickel-containing Alloys

See abstract on p. 170.

Electrical Resistance of Metallic Films

R. B. BELSER and W. H. HICKLIN: 'Temperature Coefficients of Resistance of Metallic Films in the Temperature Range 25° to 600°C.'

Jnl. Applied Physics, 1959, vol. 30, Mar., pp. 313–22.

The experiments described in this paper were designed to establish data for the electrical-resistance behaviour of metallic films over a wide range of temperature and for films of widely varying thickness, 75° to 2000 Å. It is pointed out that, irrespective of the method of deposition by which the films are produced, thin metal films are in a state of strain which is not characteristic of the bulk metal as it crystallizes from the melt. This condition is one which is thermodynamically unstable: hence, changes in the films usually occur in the course of time and/or with exposure to temperatures higher than those experienced during the formation and growth. In addition, films are subject to agglomeration due to surface forces and to reaction with elements of the environment in which they are heated. A further factor, as is shown in this paper, is the effect of inclusions, such as foreign atoms or chemical compounds of the metal under study.

In the work reported, the temperature coefficients of resistance (TCR) of films of sputtered gold, iridium, molybdenum, nickel, palladium, platinum, rhodium, tantalum and tungsten: of evaporated aluminium, chromium, titanium and zirconium, and of the alloy films platinum-gold, platinum-iridium

and platinum-nickel were measured *in vacuo* over the range of temperature and thickness indicated above. In general, the TCR values of the substantially pure metals examined were in the range $\frac{1}{3}$ to $\frac{2}{3}$ those of the respective bulk metals, irrespective of the substrate used (glass, 'Vycor' or 'Stupalith'). The difference in the conditions of growth of the films from those obtaining during production of bulk metal, i.e., rapid-cooling effects, and impurities present, contributed imperfections which reduced the TCR of the films. The TCR values of alloy films were low, 0·0004 per C.° for gold-platinum, and resistivities were 3–4 times that of either constituent. Values for sputtered films of molybdenum, tungsten and tantalum and of evaporated chromium, zirconium and titanium were generally less than 0·0001 per C.°; electron-diffraction examination revealed the presence of oxide inclusions in these films, which reduced the T.C.R. In the high-temperature tests, only films of gold, platinum and iridium were resistant to oxidation in air at 600 C.

Electrical Conductivity of Copper-base Sand-Cast Alloys

D. G. SCHMIDT and F. L. RIDDELL: 'Electrical Conductivity of Sand-Cast Copper-base Alloys.' *Modern Castings*, 1959, vol. 35, Apr., pp. 69–87.

Preprint of paper for International Foundry Congress, April, 1959.

In view of the lack of authenticated published data on the electrical conductivity of the copper-base alloys commercially produced, a systematic investigation was undertaken in the laboratories of H. Kramer & Company, Chicago. The scope of the information reported as a result of the tests (see below) indicates that the paper comprises a 'data book' on the subject.

Resistance-measurement equipment and technique are described, selection of test specimen is discussed, and detailed tables show electrical conductivity values for:

Standard A.S.T.M. Copper-base Alloys.
Sand-cast Tin Bronzes and Leaded Tin Bronzes.
„ High-Lead Tin Bronzes.
„ Leaded Red Brass and Leaded Semi-Red Brass.
„ Yellow Brass.
„ High-Strength Yellow Brass (Manganese Bronze).
„ Aluminium Bronzes (with and without nickel).
„ Nickel Silvers (9, 12, 15, 18, 20 and 25 per cent. nickel grades).
„ Copper-Nickel Alloys (12, 28 and 30 per cent. nickel grades).
Cast Silicon Bronzes and Silicon Brasses.

As a supplement to determinations of the conductivities of the respective alloys, the investigation included a study of the influence of individual elements in various types of copper-base alloy. The resulting data are shown in a series of graphs and tables indicating:

Effect of alloying elements on electrical conductivity of copper.
„ „ tin+nickel on electrical conductivity of bronzes and brasses.
„ „ phosphorus on electrical conductivity of leaded tin bronze.
„ „ copper and tin on electrical conductivity of yellow brass.
„ „ copper on electrical conductivity of manganese bronze.
„ „ aluminium on electrical conductivity of aluminium bronze.
„ „ silicon on electrical conductivity of silicon-base alloys.

Some correlation is made with electrical-conductivity values which have been reported in the literature.

Development of Nickel-Aluminium Heat-Resisting Alloys

See abstract on p. 187.

Influence of Trace Elements on Properties of High-Purity Nickel

See abstract on p. 171.

Ageing Reactions in Gold-Nickel Alloys

J. SIVERTSEN and C. WERT: 'Ageing in Au-Ni Alloys.' *Acta Metallurgica*, 1959, vol. 7, Apr., pp. 275–82.

The findings of early investigators of the gold-nickel alloy system gave rise to the conclusion that precipitation during ageing from the as-quenched condition occurred as a result of a discontinuous reaction involving decomposition of the initial solid solution to form a mixture of gold-rich and nickel-rich solid solutions. Later studies indicated, however, that the ageing behaviour of these alloys was more complex than had at first appeared. The work now reported, carried out on an alloy containing 70 per cent. of gold, throws more light upon the phenomena occurring during low-temperature annealing.

Changes in structure of the quenched alloy during ageing were determined by study of corresponding variations in electrical resistance, volume, and Young's modulus.

The data obtained indicate that at least one metastable phase is formed before the main phase-change occurs. Identification of this phase, which forms about 10^4 times earlier than the main phase and is unstable above a temperature of about 225°C., was not possible, but it appeared to consist either of clusters of gold-rich or nickel-rich atoms or of regions of high geometrical order. Quenched-in vacancies are presumed to govern the rate of the reaction, but the authors consider that the precipitate does not consist simply of clusters of vacancies.

Precipitation Phenomena in Nickel-Titanium Alloys

See abstract on p. 186.

Oxidation of Nickel-Cobalt Alloys in the Range of Curie Temperatures

W. W. SMELTZER: 'Oxidation of Nickel-Cobalt Alloys in the Range of Curie Temperatures.'

Acta Metallurgica, 1959, vol 7, Mar., pp. 191–8.

Considerable evidence has been put forward in support of the view that the kinetics of metal oxidation are altered by variation in the properties of the metal substrate: the different oxidation rates exhibited by metal surfaces of different crystal orientation, the discontinuities observed in oxidation rates at metal-lattice transformation temperatures, and the variations in oxidation characteristics of metals and alloys above and below the Curie temperature, all findings which are relevant in this connexion, are briefly reviewed by the author. The investigation now reported was conducted to throw further light on the influence, on the oxidation characteristics of metallic materials, of the magnetic state of the metal substrate.

Two high-purity nickel-cobalt alloys, containing respectively, 10·5 and 25·1 per cent. of cobalt, were selected for study. (Since nickel and cobalt form a continuous series of solid solutions, the Curie temperatures are associated only with second-order electronic transitions and not with changes in lattice structure.) The alloys were metallographically polished and then oxidized at temperatures covering the range 400°–800°C., i.e., below and above the Curie temperature. Weight gains were determined continuously, using a vacuum microbalance assembly, and oxide formation on the alloy was studied as a function of time and temperature at a constant oxygen pressure.

In the paper the results are analysed by means of time laws, using, as datum, results for oxidation of nickel. The author summarizes the main conclusions as follows:

'The oxidation rates of nickel were increased by addition of cobalt. For the film thicknesses investigated, the rates of oxidation approximated initially to a cubic law, and at longer times to a parabolic law. Above the Curie temperatures the Arrhenius temperature coefficients of the cubic and parabolic constants for nickel and the nickel-cobalt alloys were linear. The 25·1 per cent. cobalt alloy showed an anomalous oxidation characteristic: the temperature coefficients of the oxidation constants changed continuously in a temperature range extending approximately 80°C. below and to the Curie temperature. It is suggested that these variations are associated with the transformation from the ferromagnetic to the paramagnetic state, and that electronic properties of the metal substrate influence the rate-determining reaction step of metal-ion diffusion through vacancies in the surface oxide layer.'

Wear- and Galling-Resistant Nickel-Copper-Silicon Alloys

SOC. AUTOMOTIVE ENGINEERS: 'Alloy Castings, Sand and Centrifugal, Corrosion- and Heat-Resistant.'

S.A.E./A.M.S. Specification 4892, issued Jan. 15, 1959.

The specification is primarily concerned with parts required to show resistance to wear and galling under light-to-medium loads against dissimilar materials of higher hardness, and retention of hot hardness up to 1000°F. (540°C.). Composition limits are as follows: nickel+cobalt 60·0 min., copper 27·0–31·0, silicon 3·5–4·5, iron 2·5 max., manganese 1·5 max., cobalt (if determined) 1·0 max., carbon 0·25 max., sulphur 0·015 max., per cent. Condition in which supplied: as cast, having Brinell hardness (in material over ¼ in. in section) not lower than Brinell 275 or equivalent.

See also *Specification A.M.S.* 4893, issued Jan. 15, 1959, which covers material of the same composition, but in either the solution-treated condition, having a hardness not greater than Brinell 270 or equivalent, or in the precipitation-hardened condition, with hardness not lower than Brinell 300 or equivalent.

Preparation of Metallographic Specimens

See abstract on p. 171.

Identification of Corrosion Products on Copper Alloys

See abstract on p. 195.

Determination of Nickel, Zinc and Aluminium in Bronze

B. ALFONSI: 'Determination of Ni, Zn and Al in Bronzes and Brasses after Determining Cu-Pb-Sn-Sb by Controlled-Potential Electrolysis.'

Analytica Chimica Acta, 1959, vol. 20, Mar., pp. 277–82.

A method for the determination of copper, lead, tin and antimony by controlled-potential electrolysis, and the application of the method to the analysis of some alloys, particularly bronzes and brasses, have been described in previous papers (*ibid.*, 1958, vol. 19, pp. 276, 389 and 569).

Further investigations have led to elaboration of the method, permitting successive determination of nickel, zinc and aluminium, using the solution remaining after electrolytic separation of the four metals mentioned above. Nickel is precipitated by dimethylglyoxime in a slightly ammoniacal medium: in the filtrate, zinc is separated by controlled-potential electrolysis. The solution is subsequently treated with 8-hydroxyquinoline, to separate aluminium, which, after filtration and dissolution of the oxinate, is precipitated with ammonium benzoate. Full working details are given.

Determination of Nickel in Gold-Nickel Alloys

See abstract on p. 172.

Machining of Nickel and High-Nickel Alloys

INTERNATIONAL NICKEL CO., INC.: 'Machining Inco Nickel Alloys.'

Tech. Bulletin T-12, published 1959; 41 pp.

The bulletin gives details of procedures recommended for machining the following materials: (*in wrought form*) nickel, low-carbon nickel, 'Duranickel', 'Monel', 'Monel 402', 'Monel 403', 'R Monel', 'K Monel', 'Inconel', 'Incoloy', 'Incoloy T', 'Nimonic 75', 'Ni-O-Nel'; (*in cast form*) nickel, 'G nickel', 'S nickel', 'Monel', 'H Monel', 'S Monel', 'Inconel', 'S Inconel'. The excellent corrosion-resistance of these materials is allied with high strength, ductility and hardness, properties which call for machining procedures differing in detail from those used for metals and alloys which are less tough. The correct combination of tooling, speeds, feeds and cutting compounds for each of the materials is discussed, and the text is supplemented by drawings and tabular data.

Fabrication and Design of Nickel and Nickel-Alloy Pipe and Tube

INTERNATIONAL NICKEL CO., INC.: 'Fabrication and Design of Inco Nickel and High-Nickel-Alloy Pipe and Tube.'

Tech. Bull. T-17, published 1959; 33 pp.

Nickel and high-nickel-alloy seamless and welded tubes are used extensively in the chemical and food-processing industries for such applications as pipelines, condenser and evaporator tubes, and coils for heating and cooling. The information contained in this bulletin refers, however, specifically to seamless tube processed under controlled conditions. Properties of welded and welded-and-drawn tube depend upon methods of manufacture.

The following materials are discussed, under the heads listed below: 'A' nickel, low-carbon nickel, 'Monel', 'Monel 402', 'Monel 403', 'K Monel', 'Inconel', 'Incoloy' and 'Inconel X'. With the exception of 'K Monel' and 'Inconel X' in the age-hardened condition, all these materials are readily formed or fabricated by coiling, bending, threading, expanding, welding and silver brazing, provided that due consideration is given to temper and differences in behaviour from that of other tube materials.

Properties and Treatments described

Nominal Properties and Design Considerations, including A.S.M.E. Code Requirements.

Bursting Pressures.

Expanding Condenser and Heat-Exchanger Tubes into Tube Sheets.

Van Stone Flanges: hand-threading; pipe threadings.

Welding: surface preparation; metal-arc, oxy-acetylene and inert-gas metal-arc techniques; welding tubes in tube sheets; welding castings.

Brazing.

Thermal Cutting of 'Nickel', 'Monel' and 'Inconel'.

Bending and Coiling.

Cast-Pipe Fittings.

Three appendices give particulars of forms of pipe and tube available in the materials discussed, permissible tolerances and relevant U.S. specifications.

'Monel' Roofing: Data Sheet

INTERNATIONAL NICKEL CO., INC.: 'Basic Application Data: 'Monel' Roofing Sheet.'
Published 1959; 3 pp.

Reprint of *American Institute of Architects File No.* 12.

Following the abstract relating to 'Monel' roofing on the Metropolitan Museum of Art in New York (see *Nickel Bulletin*, 1959, vol. 32, No. 4, p. 111), this brochure is of interest in that it gives information on 'Monel' roofing sheet, with respect to colour, installation procedures, cost and availability, and suggested architectural specifications. It includes data on properties and weights of the sheet in available gauges, and makes recommendations with regard to gauges of sheet for specific roofing applications. The publication includes a list of some 50 examples of 'Monel' roofing installed on buildings in the U.S.A. during the period 1910-1958.

Spring Materials: Specifications and Design Factors

See abstract on p. 170.

New French Coinage

See abstract on p. 172

Applications of High-Nickel Alloys in the Petroleum Industry

See abstract on p. 197.

Development of Brazing Alloys for Joining 'Zircaloy' Components of Pressurized Water Reactors

See abstract on p. 199.

Welding of Copper to Stainless Steel

See abstract on p. 203.

Production of Structural Parts by Powder Metallurgy: Design Factors

See abstract on p. 169.

NICKEL-IRON ALLOYS

Directory of Nickel-Iron Alloys

INTERNATIONAL NICKEL CO., INC.: 'Directory of U.S. Producers of the Iron-Nickel Alloys.'

Published 1959; 18 pp.

The austenitic iron-nickel alloys offer a range of special properties which are of value in applications requiring low and/or closely controlled thermal expansion or particular magnetic and thermoelectric characteristics. This publication provides information on the manufacturers of such alloys in the U.S.A.

The directory is classified in two parts: Part 1 covers alloys characterized by special physical properties, which are dealt with in sections relating, respectively, to low-expansion and controlled-expansion alloys, glass-to-metal sealing alloys, and constant-modulus alloys. Part 2 is concerned with alloys having special magnetic and electrical properties, e.g., those showing high permeability in fields of various strengths, high-permeability rectangular-hysteresis alloys, alloys having constant permeability over a range of flux densities, magnetic temperature-compensation alloys and magnetostrictive alloys. The information given includes the nickel content of the respective materials, the trade names used by various producers, the names of manufacturers, the forms in which the various materials are available, and a broad indication of their uses.

Spring Materials: Specifications and Design Factors

See abstract on p. 170.

Preparation of Metallographic Specimens

See abstract on p. 171.

Determination of Nickel and Other Elements in Ferrites

D. H. WILKINS: 'The Determination of Nickel, Cobalt, Iron and Zinc in Ferrites.'

Analytica Chimica Acta, 1959, vol. 20, Mar., pp. 271-3.

Methods usually employed for separation of iron, nickel, cobalt and zinc have some disadvantages for rapid routine work. Successful application of ion-exchange separations to nickel-aluminium-cobalt-iron alloys of the 'Alnico' type indicated the possibility of developing, on that basis, an improved method for analysis of ferrites. This paper gives details of procedure in which the constituents are separated by utilizing the differences in the adsorption of their chloride complexes on a strongly basic anion-exchange resin. Each constituent is determined by the back titration of an excess of EDTA with a standard copper solution, using PAN [1-(2-pyridylazo)-2-naphthol] as an indicator.

CAST IRON

Elevated-Temperature Properties of Cast Iron

J. R. KATTUS and B. MCPHERSON: 'Report on Properties of Cast Iron at Elevated Temperatures.'

Amer. Soc. Testing Materials, Special Tech. Publn. No. 248; 90 pp.

Published by the Society, Mar. 1959. Price $4·25.

Under the aegis of the A.S.T.M./A.S.M.E. Joint Committee on Effect of Temperature on the Properties of Metals, the properties of various grades of cast iron have been investigated over the temperature range 800°-1000°F. (425°-540°C.), with the aim of assessing the relative suitability of low-alloy cast irons and ferritic S.G. iron for use, under load, at temperatures above the maximum of 650°F. (343°C.) at present specified. This publication contains the results of the investigation, notes on which have previously appeared in *A.S.T.M. Preprint* 68, June 1958. The scope of the test programme was indicated in an abstract of the preliminary report published in *Nickel Bulletin*, 1958, vol. 31, No. 9-10, p. 265. The report now published contains full details of test results and includes a *bibliography* of 46 items supporting the literature survey which was made prior to the experimental research.

CONSTRUCTIONAL STEELS

'300-M' Ultra-High-Strength Steel

INTERNATIONAL NICKEL CO., INC.: ''300-M' Ultra-High-Strength Steel.'

Published 1959; 12 pp.

Exploitation of the commercial potential of ultra-high-strength steel was hindered until relatively recently by the belief that tensile strengths greater than about 200,000 p.s.i. (90 t.s.i.; 140 kg./mm.²) were necessarily associated with brittleness. Serious attempts to develop steels of higher strengths were not made until the fallacy of this belief had been demonstrated, mainly as a consequence of work on structural materials of high strength/weight ratio intended to meet the requirements of the aircraft industry.

Alloy steels of A.I.S.I. 4340 type (nickel 1·65-2·00, chromium 0·40-0·90, molybdenum 0·20-0·30, per cent.) with a carbon content of 0·4 per cent. are now in service at strength levels in the range 260,000-280,000 p.s.i. (116-125 t.s.i.; 182·5-197 kg./mm.²), but this range marks the maximum strength obtainable in steels of this type. Any attempt to obtain higher strength by increasing the carbon content would deleteriously affect ductility and toughness: the other alternative, to temper at a temperature lower than that normally used (400°F.; 205°C.), would involve risk of inadequate relief of internal stresses, with consequent creation of an unstable

Longitudinal Tensile and Impact Properties of Three Commercial and Eight Experimental Heats of '300-M' Steel Tempered at 600°F. (315°C.)

Heat No.	Carbon %	Silicon %	Tensile Strength	Yield Strength 0·2% Offset	Elongation %	Red. of Area %	Hardness Rockwell C	Charpy V-Notch ft.-lb., at		
								75°F	−50°F	−100°F
Commercial Heats										
1	0·43	1·55	298,000 p.s.i. 133 t.s.i. 209 kg./mm.²	255,500 p.s.i. 114 t.s.i. 179 kg./mm.²	9·3	35·0	55	14	10	9
2	0·38	1·57	286,900 p.s.i. 128 t.s.i. 201 kg./mm.²	239,300 p.s.i. 107 t.s.i. 168 kg./mm.²	10·7	42·4	53·5	16	15	14
3	0·35	1·44	260,000 p.s.i. 116 t.s.i. 182 kg./mm.²	215,500 p.s.i. 96 t.s.i. 151 kg./mm.²	12·5	48·3	51	18	17	17
Experimental Heats*	0·40	1·66	292,600 p.s.i. 130 t.s.i. 205 kg./mm.²	245,700 p.s.i. 109 t.s.i. 172 kg./mm.²	9·7	33·9	54	15	14	13

* Average of duplicate or triplicate tests on eight 30-lb. (14-kg.) experimental induction-furnace heats.

condition. (It has been established that for reasonably complete relief of stresses a tempering temperature in the region of 600°F. (315°C.) is required.) Much research is being devoted to overcoming these problems, and this paper gives an account of work done in this connexion by The International Nickel Company, Inc.

The dual problem involved, limitation of carbon content and provision of adequate stress relief without risk of '500°F. embrittlement', has been solved by development of a composition adjusted to give higher strength with acceptable carbon and to permit use of a tempering temperature of 600°F. (315°C.) without causing softening. Information on the steel so evolved is contained in this bulletin: the material has been designated '300-M'.

Since its development in 1953 the steel has been extensively tested in the aircraft and other industries, and it is now available in the U.S.A. in the form of billets, bars, forgings, sheet, strip, plate and castings. The nominal composition range is given as: carbon 0·40–0·45, silicon 1·45–1·80, manganese 0·65–0·90, sulphur 0·025 max., phosphorus 0·025 max., nickel 1·65–2·00, chromium 0·65–0·90, molybdenum 0·30–0·45, vanadium 0·05 min., per cent. (The carbon content is governed by the properties required: for a tensile strength in the range 290,000–300,000 p.s.i. (130–134 t.s.i.; 204–211 kg./mm.²) the steel should have a minimum content of 0·4 per cent. carbon; the normal specification is therefore 0·4–0·45 per cent.)

The steel is deep-hardening, and transverse ductility in heavy sections is claimed to be unusually good. The usual heat-treatment comprises normalizing at 1700°F. (925°C.), austenitizing at 1600°F. (870°C.), quenching in oil or in air, depending on section-size, and tempering at 600°F. (315°C.).

The information contained in the bulletin is presented in sections relating to composition range, tensile and impact properties,* properties in thin sections, fatigue properties, low-temperature impact strength, castings, vacuum melting, elevated-temperature properties, mass effect, the isothermal-transformation diagram, influence of retained austenite, critical temperatures, heat-treatment (normalizing and hardening, quenching, tempering, annealing, case-hardening), hot-working, decarburization, welding, hydrogen embrittlement, and treatment for prevention of embrittlement after plating. Steel of the '300-M' composition can be produced also in castings, which have properties consistent with those characteristic of the wrought form.

Influence of Deformation Prior to Transformation on the Mechanical Properties of Nickel-Alloy Steel

E. B. KULA and J. M. DHOSI: 'Effect of Deformation Prior to Transformation on the Mechanical Properties of 4340 Steel.'

Trans. Amer. Soc. Metals, 1958, vol. 52, *Preprint No.* 29; 18 pp. + figures.

In 1954 LIPS and VAN ZUILEN reported the achievement of remarkable increases in the tensile strength, with high reduction in area, of a low-alloy nickel-chromium steel which had been hot-quenched, rolled to strip below the recrystallization temperature,

* See table above.

to transform the austenite into martensite and/or bainite, and finally quenched to room temperature. Since that date investigations of the properties of steels so treated, and of the significance of the treatment itself, have continued (see, for example, paper by SCHMATZ and ZACKAY, abstracted in *Nickel Bulletin*, 1958, vol. 31, No. 12, p. 325).

The investigation now described was carried out on a steel of A.I.S.I. 4340 type, which in the normally heat-treated condition has a tensile strength in excess of 200,000 p.s.i. (89·5 t.s.i.; 140·5 kg./mm.²). The composition of the heat studied is given as carbon 0·385, silicon 0·28, manganese 0·62, sulphur 0·013, phosphorus 0·02, nickel 1·75, chromium 0·81, molybdenum 0·23, aluminium 0·059, vanadium trace, oxygen 0·004, nitrogen 0·008, hydrogen 0·00003–4, per cent. The specimens were deformed by rolling at either 1000° or 1550°F. (540° or 845°C.), i.e., at temperatures below and above the critical. Before rolling, the specimens were austenitized at 1550°F. (845°C.) for ½ hour. Some were then rolled, at that temperature, to the desired reduction, and quenched. In the absence of a suitable salt or lead pot, the specimens deformed at 1000°F. (540°C.) were air-cooled to that temperature, stabilized for 2 minutes in a muffle furnace, and then rolled and quenched. The specimens were subjected to reductions of up to 72 per cent.: results of tensile and impact tests are plotted as a function of percentage reduction for the various tempering temperatures. Comparative data were obtained from similar tests on the steel after conventional heat-treatment.

The deformation treatment resulted in substantial improvements in the strength and ductility of the steel, but not to the phenomenal extent reported by Lips and van Zuilen.

Rolling at 1550°F. (845°C.) to achieve a reduction of up to 72 per cent., followed by quenching, had no effect on the ultimate tensile strength, but increased the 0·2 per cent. yield strength (from 205,000 to 255,000 p.s.i.; 91 to 114 t.s.i.; 144 to 179 kg./mm.²). Tempering at 400°F. (205°C.) produced a smaller improvement. The treatment had a beneficial effect on impact strength, in that it lowered the transition temperature, increased the energy level below and above the transition range, and reduced susceptibility to 500°F. (260°C.) embrittlement.

Deformation at 1000°F. (540°C.), with corresponding increase in the severity of the cold work, proved more efficacious than rolling at 1550°F. (845°C.). Treatment at the lower temperature improved the ultimate tensile strength and the 0·2 per cent. yield strength of the steel, both in the as-quenched condition and after tempering. After tempering at 425°F. (218°C.) yield strength increased from 235,000 to 280,000 p.s.i. (105 to 125 t.s.i.; 165 to 197 kg./mm.²) and tensile strength from 275,000 to 310,000 p.s.i. (123 to 138 t.s.i.; 193 to 218 kg./mm.²). Impact properties were somewhat impaired.

The advantages offered by the hardening technique investigated are offset, in certain applications, by the fact that, after quenching, the steel has a hardness of Rockwell C56 or 57, which, even after low-temperature tempering, does not fall to less than R_c50. Such high hardness precludes most machining operations and in most cases only grinding is practical. The technique would be used to greatest advantage for small fabricated sections, such as strip, sheet, wire, or extrusions (which would be quenched on a continuous basis), or on forgings capable of being quenched directly upon leaving the die.

Effect of Heat-Treatment and of Fabrication on Nickel-Alloy Pressure-Vessel Steels

A. I. RUBIN, J. H. GROSS and R. D. STOUT: 'Effect of Heat-Treatment and Fabrication on Heavy-Section Pressure-Vessel Steels.'

Welding Jnl., 1959, vol. 38, Apr., pp. 182s–7s.

In a previous investigation the authors had studied the effects of accelerated cooling from the austenitizing temperature, on the tensile properties and notch toughness of a group of carbon and low-alloy steels used or under consideration for heavy-walled pressure vessels (*ibid.*, 1958, vol. 38, pp. 160s–8s). The results of those tests showed that improvement in both strength and toughness can be obtained by accelerated cooling after austenitizing, followed by re-heating to suitable stress-relief temperatures. The work has now been extended to determine the nature and extent of alterations, in the properties so obtained, which would result from fabrication operations such as cold working and prolonged stress-relief treatments. The steels used in both sections of the investigation were representative of A.S.T.M. standard types of carbon, carbon-silicon, nickel, manganese-molybdenum and chromium – molybdenum boiler-plate steels, and included also a 1 per cent. manganese steel, a nickel-copper-molybdenum type ('HY-65'), a complex nickel – chromium – manganese – molybdenum-vanadium type ('T-1') and a low-carbon nickel – chromium – molybdenum steel designated 'HY-80'.

Two basic conditions of heat-treatment were used for each of the steels, to reproduce the microstructures characteristic, respectively, of a normalized 4-in. (10-cm.) thick plate and a point near the surface of a spray-quenched 4-in. (10-cm.) plate. Full details of that treatment are given, the specialized heat-treatments recommended in the earlier investigation are described, and particulars are given of the stress-relief and fabrication procedures which were under study.

Charts and tables show the effects of long-time (up to 100-hour) stress-relief treatments and of strain-ageing. The reaction of the respective steels to the thermal and mechanical treatments used lead to the following conclusions:

In both carbon and alloy steels, extended times of stress-relief produced loss of strength and increase in ductility. With most of the steels long stress-relief treatments caused little change in notch toughness. After treatment for 100 hours two of the

alloy steels showed a rise of 100F°. (55C°.) in transition temperature.

All the steels were susceptible to strain-ageing, but all the standard stress-relief treatments obliterated practically all the embrittlement induced by pre-straining.

The authors emphasize that the accelerated cooling treatment, which had been shown to improve the properties, did not introduce any greater sensitivity to fabrication operations or stress-relief treatment than is found in steels not subjected to the specialized thermal cycle. In general, the results of the tests suggest that the improvements in strength and notch toughness obtainable from accelerated cooling and from use of alloy steels are not jeopardized by the fabrication operations studied.

Influence of Nickel on High-Speed Tool Steels

R. F. HEHEMANN and A. R. TROIANO: 'How Nickel Affects High-Speed Tool Steels.'

Reprint of article from *Iron Age*, 1958, vol. 182, Dec. 18 and 25.

Issued by INTERNATIONAL NICKEL CO., INC., 1959; 8 pp. For abstract see *Nickel Bulletin*, 1959, vol. 32, No. 4, p. 113.

Preparation of Metallographic Specimens

See abstract on p. 171.

Production of Structural Parts by Powder Metallurgy: Design Factors

See abstract on p. 169.

Determination of Titanium, Zirconium, Niobium and Tantalum in Steels

J. L. HAGUE and L. A. MACHLAN: 'Determination of Titanium, Zirconium, Niobium and Tantalum in Steels: Separations by Anion-Exchange.'

Jnl. Research, Nat. Bur. Standards, 1959, vol. 62, Jan., pp. 11–19; *R.P.* 2923.

The procedure described provides for determination of the elements named, in amounts ranging from a few thousandths of one per cent. to approximately 0·5 per cent.

The elements are concentrated by selective precipitation with cupferron from a hydrochloric-acid solution of the sample, and then ignited to the oxides. The oxides are fused, and dissolved in a hydrochloric/hydrofluoric acid mixture. Three separate eluates, containing titanium and zirconium, niobium, and tantalum, result from elution with mixtures containing ammonium chloride, hydrochloric acid, and hydrofluoric acid from a column of Dowex-1 anion-exchange resin. Boric acid is added to the eluates to complex the hydrofluoric acid, and the elements are precipitated with cupferron. Titanium is determined by the hydrogen-peroxide method, and zirconium by the phosphate-gravimetric method. Niobium and tantalum are determined by the hydroquinone- and pyrogallol-photometric methods, or by weighing the oxides.

Reproducibility of the results obtained by use of the recommended procedure is illustrated by data tabulated for determinations made on low- and high-alloy N.B.S. standard steels; *inter alia*, various 18–8-type chromium-nickel stainless steels.

Low-Alloy Nickel-containing Steel for Welded Bridge Construction

'Double Cantilever Bridge over the Carquinez Strait in California.'

Engineer, 1959, vol. 207, Apr. 17 and 24, pp. 630–3, 669–71.

The information given is cognate with, but more detailed than, that which appeared in *Welding Jnl.*, 1958, vol. 37, Apr., pp. 309–19: *see* abstract in *Nickel Bulletin*, 1958, vol. 31, No. 7, p. 193.

American Developments in Investment-Cast Materials

See abstract on p. 170.

Testing of Hot-Cracking Susceptibility of Welds

See abstract on p. 205.

Nickel-containing Steels for Low-Temperature Applications in the Petroleum Industry

See abstract on p. 196.

HEAT- AND CORROSION-RESISTING MATERIALS

Dispersion-Hardening of Sintered Nickel-Chromium Alloys

E. GREGORY, M. EPNER and C. G. GOETZEL: 'Research on Heat-Resistant Alloys Strengthened at Elevated Temperatures by Incorporation of Fine Particulate Substances.'

U.S. Navy Bureau of Aeronautics Report, Dec. 1956; 26 pp.; recently declassified.

The information contained in the report, which represents a summary of work carried out on the dispersion-hardening of 80–20-type nickel-chromium alloys, is generally cognate with that recorded by GREGORY and GOETZEL in *Trans. Metallurgical Soc., Amer. Inst. Mining and Metallurgical Engineers*, 1958, vol. 212, Dec., pp. 868–74 (see abstract in *Nickel Bulletin*, 1959, vol. 32, No. 3, pp. 86–7).

Precipitation Phenomena in Nickel-Titanium Alloys

C. BÜCKLE, B. GENTY and J. MANENC: 'Some Aspects of Precipitation in a Nickel-Titanium Alloy.'

Revue de Métallurgie, 1959, vol. 56, Mar., pp. 247–59.

The alloy studied (nickel with 9·26 per cent. titanium) was one of a series of nickel-base alloys

examined by the authors in an attempt to throw further light on the precipitation phenomena involved in age-hardening of heat-resisting 80-20 nickel-chromium-base and related alloys. An earlier paper in the series was abstracted in *Nickel Bulletin* 1959, vol. 32, No. 4, p. 115.

The specimens were solution-treated at 1275° or 1080°C., cold-worked, re-crystallized at 1080°C., quenched, and finally aged for various times at temperatures in the range 600°-800°C. Precipitation occurring in the specimens was studied by X-ray techniques, and by electron and optical microscopy.

When the precipitate present corresponded to the stable hexagonal phase Ni_3Ti, precipitation took place in three stages: (1) a pre-precipitation stage involving abnormal diffusion; (2) precipitation of an unstable slightly tetragonal face-centred-cubic phase; (3) formation of the stable hexagonal phase, partly within the grains in the form of coherent plates following the [111] planes, and partly at the grain boundaries. Discussion of the results is supplemented by reference to numerous photomicrographs.

'Hastelloy N': New Heat- and Corrosion-Resisting Alloy

F. S. BADGER: 'New 'Alloy N' Joins Hastelloy Family.'

Chemical Engineering, 1959, vol. 66, May 4, pp. 162, 164, 166.

In recent years work has been in progress at Oak Ridge National Laboratory on the development of materials suitable for use in nuclear-power reactors fuelled with fused uranium-bearing fluoride salts. Emphasis was placed on resistance to corrosion by the fluoride salts, oxidation-resistance in air, adequate mechanical properties at the high temperatures involved, and satisfactory nuclear characteristics. Of the commercial alloys available, the 80-14-6 nickel-chromium-iron alloy 'Inconel' and the 67-28-5 nickel-molybdenum-iron alloy 'Hastelloy B' offered the greatest potential in this respect: both possessed desirable characteristics, but neither was fully satisfactory. A compromise solution to the problem was sought in nickel-base alloys containing strengthening additions of 15-20 per cent. of molybdenum and minor amounts of other elements.

Screening tests (see *O.R.N.L.* reports referred to in *Nickel Bulletin*, 1957, vol. 30, No. 6, p. 99 and No. 7-8, p. 131; *ibid.*, 1958, vol. 31, No. 12, p. 343) showed that, on the basis of strength, workability, weldability and corrosion- and oxidation-resistance, the most suitable alloy was that designated 'Inor-8'. Further experiments on alloys covering a composition range wide enough to include that of 'Inor-8' led the investigators to confirm the pre-eminence, in relation to the properties and application considered, of the 'Inor-8' composition (see abstract of the relevant report in *Nickel Bulletin*, 1959, vol. 31, No. 3, p. 85). This alloy is now in commercial production by Haynes Stellite Company and has been designated 'Hastelloy Alloy N'. Its composition range is given in Table I, together with those of 'Hastelloy B' and 'Inconel'.

The present article includes comparative data on the mechanical properties, physical properties and resistance to oxidation and corrosion of 'Hastelloy N', 'Hastelloy B' and 'Inconel'. The text relates mainly to the modifications in composition by which an optimum combination of the desired properties was achieved.

Investment Castings in 'F.V.520' Steel

R. TAYLOR: 'Development of Corrosion-Resisting Investment Castings with Higher Mechanical Properties and Good Weldability.'

Foundry Trade Jnl., 1959, vol. 106, Apr. 9, pp. 414-16; disc., pp. 416-17.

In recent years the demand for investment-cast components of high tensile strength has led to the extension of the lost-wax casting process to a much wider range of materials than those alloys to which originally it was mainly applied. This article, which is based on a paper presented at the 1958 European Investment Casters' Congress, reviews recent developments in this connexion, in particular, the introduction of a heat-treatable steel suitable for investment-casting.

The application of the process to the ferritic and martensitic grades of steel gave rise to problems (which the author outlines) concerned not only with the castability of the steels, but also with their welding properties, and with the deleterious effects, on corrosion-resistance or, in the case of low-alloy steel, on precision dimensions, of heat-treatment applied to obtain the required mechanical properties. Experience demonstrated that the answer to these problems would be found only in development of a steel which was: (1) heat-treatable to give high yield or proof

Compositions of 'Hastelloy N', 'Hastelloy B' and 'Inconel'

	Ni %	Mo %	Cr %	Fe %	Si %	Mn %	C %	Other Elements %
'Hastelloy alloy N'	Bal.	15-18	6-8	5 max.	0·5 max.	0·8 max.	0·04-0·08	B 0·01 max. Al+Ti: 0·5 max.
'Inconel'	Bal.	—	14-17	6-10	0·5 max.	1·0 max.	0·15 max.	Cu 0·5 max.
'Hastelloy B'	Bal.	26-30	1·0 max.	4-7	1·0 max.	1·0 max.	0·05 max.	V 0·20-0·60 Co 2·5 max.

stress with adequate ductility, (2) highly corrosion-resistant, (3) satisfactorily weldable, and (4) readily cast by the investment process. The first three of these criteria were already satisfied by the 'F.V.520' steel developed by Firth-Vickers Stainless Steels, Ltd. (for composition, see *Nickel Bulletin*, 1957, vol. 30, No. 12, p. 227). Work was then initiated to modify the composition of that steel in order to meet the fourth requirement. That these experiments met with success is shown in the data presented in the article. The information given is based on results of tests on separately-cast test pieces and on specimens cut from an investment casting; it illustrates, *inter alia*, the high mechanical properties of investment-cast 'F.V.520', in particular, the good yield strength, which is an asset from the designer's point of view.

Development of Nickel-Aluminium Heat-Resisting Alloys

F. EISENKOLB and H.-E. RÖLLIG: 'The Development of Heat-Resisting Ni-Al-base Materials.'

Neue Hütte, 1959, vol. 3, Dec., pp. 721-31.

The paper relates to experiments carried out by the authors to investigate the suitability of various nickel-aluminium alloys for use as heat-resisting materials and to develop methods of producing and working them. Particular attention was paid during the investigation to compositions based on the intermetallic phase NiAl, the melting point of which (about 200C°. higher than that of nickel) offered promise in high-temperature applications.

In preliminary tests an attempt was made to produce alloys suitable for study in the main phase of the investigation. Vacuum-melting and -casting was eventually found to be the most effective method of meeting the requirements, and the eight alloys so produced (containing 20-70 at. per cent. nickel) were subjected to microscopical and X-ray examination. Alloys with 50-60 at. per cent. of nickel were found to be single-phased: with a nickel content of 50 per cent. an intermetallic compound of the formula NiAl occurred and at 60 per cent. a solid solution formed between the nickel and nickel aluminide. (The NiAl phase (m.p. 1640°C.) was also present in the 70 per cent. nickel alloy). Additional intermetallic phases were distinguished in the remaining alloys.

Further investigations were concerned with the powder-metallurgical production of nickel-aluminium alloys with nickel contents approaching that of the intermetallic compound NiAl and with examination of the alloys so produced. The alloy powders used were obtained by grinding the vacuum-melted alloys or, where this procedure was not successful, by pulverizing the molten alloy in a stream of compressed air. Compacts were made also from mixed nickel and aluminium powders used in elemental form.

Two methods of processing the compacts were studied: (1) cold pressing, followed by sintering in a hydrogen environment; (2) hot pressing, at various pressures and temperatures.

In the final stage of the investigation the processed specimens were subjected to metallographic examination and to tests which involved determination of density, Vickers hardness, and tensile (or compressive) strength at room temperature and, in some cases, of bend strength at 900°C. Oxidation tests were carried out in a stream of air at 900° and 1250°C., for times up to 250 hours. The data obtained are presented in detail and the paper includes many photomicrographs of the specimens.

The best results were obtained in compacts obtained by hot pressing at 1000°-1200°C. and 600 kg./mm.^{2}, but direct production of nickel-aluminide specimens by the same technique, using elemental powders, was found to be impossible, due to melting induced during the reaction. The authors' findings did not adequately resolve the question as to the relative efficacy of sintering nickel-aluminide powders *per se* or of forming the phase during sintering viâ a low-nickel and a high-nickel constituent. The results of all the tests did, however, show that it is not possible to produce a satisfactorily ductile material from the intermetallic compound NiAl by powder-metallurgy techniques.

Findings with respect to the nickel-rich alloys studied were more rewarding. The alloy containing 70 at. per cent. of nickel had not only a certain ductility, but also an oxidation-resistance comparable to that of nickel aluminide: the main disadvantage of such material lies in its high nickel content. It is tentatively suggested that nickel-aluminide-base heat-resisting materials mentioned in the literature may owe their properties more to a nickel-rich compound than to the NiAl phase.

Heat-Resisting Cast Nickel-Chromium-Iron Alloys

E. A. SCHOEFER: 'A Selection Guide to Heat-Resistant Cast High Alloys.'

Machine Design, 1959, vol. 31, Apr. 2, pp. 119-25.

The advantages of cast materials for use at temperatures in the range 1200°-2200°F. (650°-1205°C.) are briefly discussed, and a review is made of factors governing selection of the most suitable composition for specific applications.

The article is based on a consideration of materials falling within the range of nickel-chromium-iron alloys covered by the 'H' series standardized by the Alloy Casting Institute. Nominal compositions are tabulated and the properties and uses of the materials are discussed in three groups representative, respectively, of alloys containing 8-30 per cent. chromium, and less than 7 per cent. nickel; 19-32 per cent. chromium and 8-22 per cent. nickel; 10-23 per cent. chromium and 23-68 per cent. nickel.

Five factors are taken into account in the author's assessment of the relative ability of these materials to withstand the wide range of conditions implied in the term 'high-temperature service': surface stability, structural stability, mechanical properties, physical properties and design considerations. Under the heading 'surface stability' some indication is

given of relative corrosion-resistance in hot gaseous environments. Structural stability is discussed principally in relation to the significance, in this respect, of close control of composition, while the main emphasis in the section on mechanical properties is on thermal-fatigue characteristics and factors governing design stress. Thermal, magnetic and electrical properties are briefly reviewed and the article closes with a section in which design considerations are summarized in terms of the castability, fabrication and cost of the casting materials.

The figures supplementing the textual review form an interesting and useful feature of the article. Data on each alloy are presented diagrammatically, to provide a ready means of comparing the various materials on the basis of corrosion-resistance in air and in oxidizing and reducing flue gas, room-temperature and short-time and long-time elevated-temperature mechanical properties, thermal conductivity and thermal expansion, and cost.

'AM-350' and 'AM-355' Stainless Steels: Heat-Treatment and Properties

R. A. LULA: ''AM-350' and 'AM-355': Properties and Heat-Treatment.'

Metal Progress, 1959, vol. 75, Mar., pp. 116–20.

'AM-350' heat-resisting steel is of the following nominal composition: carbon 0·1, silicon 0·3, manganese 0·75, chromium 16·5, nickel 4·25, molybdenum 2·75, nitrogen 0·1, per cent. The composition of 'AM-355' steel differs only in that the carbon content is increased to 0·15 per cent. and the chromium lowered to 15·5 per cent. In the annealed state both steels are austenitic and, as annealed, their formability and weldability are comparable to those of other austenitic steels: in the hardened condition they are martensitic. The different carbon and chromium contents result, however, in differences in structure (the 'AM-355' grade is practically free from delta ferrite, whereas 'AM-350' contains 10–20 per cent. of that phase). These structural differences are reflected in the mechanical properties. In this article the two steels are compared on the basis of heat-treatment, structure and mechanical properties.

A résumé of the influence of annealing temperature on the M_S temperature, and hence on austenite stability, leads to discussion of the heat-treatments used to harden the steels. (These treatments were described by GILBRAITH in *Metal Treatment and Drop Forging*, 1957, vol. 24, Oct., pp. 395–9: details will be found in the relevant abstract in *Nickel Bulletin*, 1958, vol. 31, No. 2, pp. 52–3.) Mechanical properties obtainable by the various treatments are tabulated and structural variations in different conditions of heat-treatment are exemplified by reference to photomicrographs.

The last part of the article is concerned with a short review of the heat-treatments used to obtain optimum properties in the two steels in sheet, bar and castings. Typical room- and high-temperature properties of 'AM-355' are given and similar data supplement notes on the high strengths obtainable as a result of cold rolling.

See also following two abstracts:

Fabrication of 'AM-355' Steel

G. N. AGGEN: ' 'AM-355': High-Strength Stainless.'

Iron Age, 1959, vol. 183, Apr. 2, pp. 74–7.

In the context of the assertion that, 'depending upon heat-treatment, 'AM-355' can be made to resemble either an austenitic stainless steel such as A.I.S.I. Type 301 or a hardenable stainless steel such as A.I.S.I. Type 410', the author is concerned mainly with the heat-treatment and procedures which give optimum results in forging, machining and welding the steel. The article also contains notes on mechanical properties and corrosion-resistance (supplemented by data on short-time tensile characteristics, impact strength, and stress-rupture and creep properties).

'AM-350' Steel: Corrosion-Fatigue Properties and Resistance to Corrosion by Sea Water

W. L. WILLIAMS: 'Salt-Water Corrosion and Corrosion-Fatigue Properties of Allegheny Ludlum 'AM-350' Alloy.'

U.S. Naval Engineering Experiment Station, Evaluation Report 040034J, *N.S.* 013-123, May 31, 1956; 7 pp. Declassified 1958.

The tests were carried out on two lots of steel. The first had been hardened by refrigeration for 20 minutes at −100°F. (−73°C.) followed by tempering for 2 hours at 750°F. (400°C.); the second had been refrigerated for 2 hours and tempered for 2 hours at 800°F. (425°C.). Charpy keyhole impact tests showed that ductility was retained down to −40°F. (−40°C.), the lowest temperature investigated.

Corrosion-fatigue tests were carried out, on polished cantilever specimens (from lot 1), rotating at 1,450 r.p.m., in a stream of brackish water. In the corrosion tests two unstressed and two U-bent specimens were exposed for 6 months in a trough through which sea water flowed at a velocity of about 1–1½ ft./sec. (30·5–45·5 cm./sec.).

Corrosion-fatigue strength of the steel was found to be in the region of 39,000 p.s.i. (17·5 t.s.i.; 27·5 kg./mm.^{2}) at 50 million cycles, which compares favourably with values obtained for comparable materials, including precipitation-hardening steels, in the same medium. Corrosion-resistance in sea water was good, though, as with other stainless steels, the 'AM-350' specimens were susceptible to severe local crevice attack. No evidence of stress corrosion was observed in the U-bent specimens.

Properties of 'PH 15-7 Mo' Age-Hardenable Stainless Steel

M. W. MARSHALL and H. TANCZYN: ' 'PH 15-7 Mo': More Strength at Elevated Temperatures.'

Metal Progress, 1959, vol. 75, Mar., pp. 121–5.

In the past decade extensive use has been made

of the Armco Steel Corporation '17-7 PH' stainless steel for structural components of aircraft. In general, however, the steel has been suitable in this connexion only for applications involving temperatures lower than about 600°F. (315°C.). With the development of high-speed aircraft, materials of construction for airframes will be required to withstand aerodynamic heating at temperatures twice as high. A modification of the '17-7 PH' steel, 'PH 15-7 Mo', which exhibits excellent tensile and compressive yield strengths and high creep-resistance up to 1000°F. (540°C.), forms the subject of the present article.

'PH 15-7 Mo' is of the following nominal composition: carbon 0·07, silicon 1 max., manganese 1 max., sulphur 0·04 max., phosphorus 0·04 max., chromium 15, nickel 7, molybdenum 2·25, aluminium 1·2, per cent. The composition differs from that of '17-7 PH' only in the inclusion of molybdenum and the decrease of the chromium content from 17 to 15 per cent. Both steels are precipitation-hardened by similar heat-treatments, which are briefly outlined. (These treatments have been described by GILBRAITH in *Metal Treatment and Drop Forging*, 1957, vol. 24, Oct., pp. 395-9: details will be found in *Nickel Bulletin*, 1958, vol. 31, No. 2, pp. 52-3.)

Notes on the properties of the steel are supplemented by tabular and graphical data illustrating (mainly with respect to the RH 950 condition) tensile properties of plate, strip and sheet in the TH 1050 and RH 950 conditions, compared with those of '17-7 PH'. Attention is drawn also to the beneficial effect, on room-temperature strength, of prior creep stressing, and information is given on short-time tensile and stress-rupture strength of sheet at 600°, 700°, 800° and 900°F. (315°, 370°, 425°, 480°C.), on long- and short-time creep-resistance, compressive yield strength and resistance to deformation. In other curves the tensile-strength/weight ratio, yield strength and compressive strength of 'PH 15-7 Mo' are compared with those of various stainless steels and alloys conventionally used as airframe materials. Corrosion-resistance of 'PH 15-7 Mo' is stated to be comparable to that of its parent material. Both steels are fabricated by the same procedures.

Influence of Fabrication on the High-Temperature Life of 'A-286' Bolts

'How to Increase High-Temperature Reliability of 'A-286' Fasteners.'

Steel, 1959, vol. 144, Mar. 16, pp. 114-17.

The relative cheapness and ease of fabrication of 'A-286' (age-hardenable austenitic 26-15 chromium-nickel steel containing small amounts of molybdenum, titanium and vanadium) have led to its wide use as a bolting material for high-temperature applications. Some failures during service have, however, been reported in such bolts. (In this connexion, reference may be made to two articles recording the results of investigations of the failure of threaded specimens to meet the stress-rupture requirements laid down in S.A.E./A.M.S. Specification 7478 for bolts and screws intended for service at temperatures up to 1200°F. (650°C.): see abstracts in *Nickel Bulletin*, 1958, vol. 31, No. 9-10, pp. 269-70.) The present article is based on the results of research by Standard Pressed Steel Company, presented by R. L. SPROAT in substantiation of the contention, by that Company, that unreliability of 'A-286' bolts may be attributed in large measure to variations in fabrication procedures. The article includes, as 'background' information, an outline of the requirements of A.M.S. Specifications 7478 and 7849, which cover the fabrication of 'A-286' bolts and screws, and notes on the variety of procedures used by manufacturers.

The Company's investigations, the results of which are outlined in the article, were directed to establishing the influence, on bolt life and performance, of solution-treatment temperature, method of forming the head and thread, surface finishing, and thread contour. The effects of fabricating operations, on the microstructure of the bolts, are shown in photomicrographs. The findings have led to the development of design and fabrication procedures which are claimed considerably to increase the fatigue and stress-rupture life of 'A-286' bolts. The procedures recommended are listed below.

Cold Working. A minimum of 15 per cent. throughout the body of the fastener is required before solution heat-treatment. Anything less may reduce stress-rupture life as much as 80 per cent.

Forged Heads. This technique gives uniform, contour-hugging metal-flow lines. Machining of heads from bar may cut stress-rupture life by 90 per cent.

Heat-Treating. Temperatures should be at least 1800°F. (980°C.). Treatment at 1650°F. (900°C.), frequently used because of furnace limitations, may reduce fastener life by 60 per cent.

Finish Grinding. This is necessary on all bearing surfaces, shank, and thread area, to remove contaminated material, much of which is a carry-over from the raw stock. Bolts made without a finish grind may have 70 per cent. less life.

Rolled Threads. The ground, milled, or cut threads permitted in some turbine specifications greatly reduce stress-rupture performance. Cut threads may lower it as much as 80 per cent.

Thread Root. A large, continuous radius is needed. (Most specifications allow threads with no radius in the root.) One thread form having a large radius in the root increases stress-rupture life sevenfold over standard aircraft threads.

Extrapolation of Creep Data on 'Inconel'

W. D. MANLY: 'Use of a Rate Equation for the Extrapolation of Creep Data.'

Oak Ridge Nat. Laboratory, *Report* 57-8-119, Aug. 20, 1957; recently declassified; 19 pp.

The report proposes a method by which creep curves for 'Inconel' sheet can be interpolated, with a high degree of accuracy, from short-time tests. The technique combines a modified Eyring rate-reaction equation and the exponential creep rate of

'Inconel'. Some reference is made to other methods which have been proposed for extrapolation of creep data: the limitations inherent in the respective procedures, and their advantages, are critically discussed. (In this connexion attention may be directed also to an appraisal of extrapolation methods prepared by BETTERIDGE: see *Jnl. Inst. Metals*, 1957–58, vol. 86, pp. 232–8: abstract in *Nickel Bulletin*, 1958, vol. 31, No. 4, p. 109.)

Influence of Rapid Thermal Cycling on Hot Ductility of 'Inconel' and 'Inconel X'

E. A. PIGAN: 'An Investigation of Hot Ductility of 'Inconel' and 'Inconel X'.

Oak Ridge National Laboratory, Report ORNL-2751, Sept. 19, 1958; 55 pp.

The aim of the investigation was twofold: (1) to study the effects, on 'Inconel' and 'Inconel X', of the rapid time/temperature cycles associated with arc welding; (2) to determine, by metallographic examination of fractured specimens, the factors responsible for the changes in properties which result from such cycling.

The investigation was carried out by means of a high-speed time/temperature controller, full details of which are given in the report. This apparatus not only enabled the specimens to be exposed to any pre-determined thermal cycle, but also provided for measurement and recording of the applied load necessary to fracture the specimen at any desired point in a thermal cycle.

The hot ductility and ultimate tensile strength of the two alloys were investigated by using thermal cycles comparable to those encountered during arc welding 1½-in. plate with 70,000 joules in-put. The test programme comprised three main phases:

(1) To determine the effect, on hot ductility, of the thermal cycles to which the heat-affected zone of the basis metal is subjected during welding, a series of specimens were fractured at temperatures representing the peak of the thermal cycle at various distances from the fusion zone of a weld. The maximum temperature of thermal cycling was raised until a temperature was reached at which ductility was reduced to zero, and that cycle was considered to be the embrittling cycle. Specimens were fractured at 1500°, 1800°, 2000°, 2200°, 2300°, 2350°, 2400°F. (815°, 980°, 1095°, 1205°, 1260°, 1285°, 1315°C.) and, in the case of 'Inconel', at 2450° and 2500°F. (1340° and 1370°C.).

(2) To determine the damage caused by exposure to the embrittling cycle (the maximum temperature of which was found to be 2450°F. (1340°C.) for 'Inconel' and 2400°F. (1315°C.) for 'Inconel X') a series of specimens were fractured while cooling from the embrittling temperature.

(3) Specimens were tested to fracture, at various temperatures, while cooling from a temperature 50F°. (28C°.) below that of embrittlement.

The results of these experiments are presented *in extenso:* the author's findings are summarized below.

As determined by the tests of phase 1, the hot ductility of both alloys increased with temperature of test, to reach a maximum at 2200°F. (1205°C.). From 2200°F. to the embrittling temperature ductility rapidly decreased. The ultimate tensile strength of the specimens decreased with rise in temperature over the range investigated.

Compared with the values determined in the first series of tests, the 'Inconel X' specimens tested in the second phase of the investigation suffered a severe loss in ductility, and tensile strength was also markedly reduced at all temperatures. A similar comparison of the 'Inconel' data reveals a general fall in ductility: nevertheless, the general trend of the results was the same, an increase up to 2200°F. (1205°C.), followed by a sharp decrease up to 2450°F. (1340°C.). At the lower test temperatures the tensile strength of the 'Inconel' specimens was decreased, but at the higher temperatures tensile values did not differ significantly from those obtained in phase 1.

Metallographic examination of fractured specimens showed that the pronounced decrease in the ductility of 'Inconel X' is accompanied by grain-boundary melting, and it is considered that this factor might contribute to hot cracking in the heat-affected zone when the alloy is welded in large sections. Grain-boundary melting in 'Inconel' was limited to an extent which would not be expected to damage the material severely.

The poor weldability of 'Inconel X' in thick sections and the satisfactory weldability of 'Inconel', as reflected in the severe or slight decrease in ductility which the respective alloys suffered during testing, would seem to indicate that the technique used in the investigation offers a satisfactory means of determining weldability.

Elevated-Temperature Properties of Cast Iron

See abstract on p. 182.

Oxidation Tests on High-Temperature Alloys

J. C. RICHMOND and H. R. THORNTON: 'Oxidation of Experimental Alloys.'

Wright Air Development Center, Tech. Report 58-164, June 1958; 49 pp.

Oxidation-resistance is obviously a property of paramount importance in determining the suitability of alloys for use in certain types of high-temperature service. Deterioration in physical and mechanical properties can occur as a result of gradual loss of thickness due to surface scaling, and even when surface scaling occurs to only a minor extent, sub-surface oxidation may cause marked deterioration in strength and other properties. In addition, there is a tendency, with some alloys, for certain constituents to be preferentially oxidized, thus

depleting the main alloy of elements which are essential for maintenance of satisfactory behaviour in service.

The investigation covered by this report was undertaken, at the National Bureau of Standards, to provide data on the oxidation-resistance of some alloys which, developed during the past few years mainly on a criterion of mechanical properties at high temperatures, are being considered for use in aircraft applications in which oxidizing conditions at high temperatures will be involved.

The materials examined, in the form of sheet of various thicknesses, were of the following types:

'Nichrome V': 80–20 nickel-chromium-base alloy

'Nichrome V', containing 4 per cent. aluminium

'Nichrome V', containing 1 per cent. niobium

Iron-chromium-aluminium alloy (Cr 25, Al 5, per cent.)

'Inconel 702' (Ni 80, Cr 15, Al 3, Ti 0·10, Nb 0·5, C 0·02, per cent.)

'Hastelloy R-235' (Cr 16·4, Mo 7·11, Al 1·31, Ti 1·90, Fe 11·1, per cent., Ni balance)

'Hastelloy W' (Mo 18–21, Fe 7–9, Cr 5, per cent., Ni balance)

Type 316 steel (18–12 Cr–Ni containing Mo)

'Inconel X' (Ni 73·77, Cr 14·88, Nb 2·35, Al 0·94, Fe 6·72, per cent.)

'Inconel' (Ni 75·69, Cr 15·19, Fe 8·54, per cent.)

Since rate of oxidation, and consequently, rate of deterioration of properties, will be affected by service conditions, the test conditions were planned to simulate service which would involve variables such as temperature, fluctuation of temperature, and stress. These requirements were provided for by the following tests:

(*a*) *Stress-Oxidation* tests, in which specimens were heated for 100 hours in air, under five different levels of stress, at each of four temperatures within the range 1500°–2500°F. (815°–1370°C.). Depth of uniform oxidation (loss of sound metal) and total depth of stringer penetration to be measured, with, if possible, determination of the type of oxidation undergone (intergranular and/or transgranular).

(*b*) *Thermal-Cycling/Oxidation* tests, in which specimens were heated for 100 hours under load at the maximum test temperature, while being cycled between 1200°F. (650°C.) and the maximum test temperature. Two different conditions of load and temperature to be used. Depth of uniform oxidation and stringer penetration to be assessed.

(*c*) *Weight-Gain Measurements*. Weight-gain to be measured continuously during the 100-hour heating period, at each of the four exposure temperatures.

Detailed records are given of the behaviour of the respective alloys in the tests, but no general direct comparison is made among them, since it is considered that such comparison can be valid only in specific service conditions. It is therefore left to individual engineers to make their own selection, based on the data recorded, duly correlated with a knowledge of particular requirements. The following comments are, however, offered:

'In the load-extension tests it was found that for each alloy there was a minimum stress above which the depth of oxide penetration varied with stress. This stress corresponded approximately to that required to produce one per cent. extension in 100 hours.

'The alloys were remarkably free from stringers over one mil in depth. The only alloys showing stringer penetration were niobium – modified 'Nichrome V', 'Hastelloy R235', Type 316 stainless steel and 'Inconel X', and for all of these alloys except niobium-modified 'Nichrome V' stringer penetration occurred at only a few combinations of temperature and stress. In every case where stringers were found, the number was small, below 30 per inch (25 mm.) of interface. All stringers noted were intercrystalline.

'Voids were found on treated sections of several of the alloys. This void formation is ascribed to diffusion to the surface, and preferential oxidation, of one of the constituents of the alloy, probably chromium.

'The 'Nichrome V' specimens showed extensive fissuring at the higher stresses at 1800° and 2000°F. (982° and 1093°C.).

'In general, the effect of fluctuating-temperature conditions upon the depth of oxide penetration was slight. In only the iron-chromium-aluminium alloy was depth of oxide penetration markedly greater under fluctuating-temperature conditions than under constant-temperature conditions, at the same stress and maximum temperature.

'All of the alloys tested were found to conform reasonably well to the parabolic rate law of oxidation, at times greater than about 30 hours.'

Oxidation of Nickel-Cobalt Alloys in the Range of Curie Temperatures

See abstract on p. 180.

Electrical Resistance of Metallic Films

See abstract on p. 178.

High-Temperature Testing: Recommended Procedures

See abstract on p. 170.

Brazed-Sandwich Structures for Aeronautical High-Temperature Applications

C. F. BURROWS and F. J. RAGLAND: 'Development of Brazed-Sandwich Construction Materials for High-Temperature Applications.'

Wright Air Development Center, Report 55-463, Pt. II, July 1958; 105 pp.

Problems associated with the aerodynamic heating to which high-speed aircraft are subjected during flight have emphasized the need for structural

materials which, while offering the high strength/weight ratios and aerodynamic properties of conventional adhesive-bonded aluminium-alloy sandwich structures, will also exhibit adequate resistance to the elevated temperatures involved. The solution of the problem appeared to lie in development of a brazed sandwich structure fabricated from a suitable stainless steel, and, encouraged by exploratory work which had demonstrated the feasibility of producing such a structure with the necessary flatness, the authors undertook the research described in the present report.

Their aims were twofold: (1) to determine combinations of skin and core material and of brazing alloy which would confer optimum resistance to temperatures up to 1200°F. (650°C.), and (2) to obtain design data on the composite structures.

Of the various heat-resisting steels commercially available, the following five were selected for preliminary study:

(1) the chromium-nickel precipitation-hardenable steel '17-7 PH',

(2) a modified 12 per cent. chromium martensitic steel (A.I.S.I. Type 422),

(3) niobium-stabilized chromium-nickel austenitic steel, '19-9 DL',

(4) niobium / titanium - stabilized chromium - nickel austenitic steel, '17-14 Cu-Mo',

(5) precipitation - hardenable nickel - chromium - austenitic steel, 'A-286', containing titanium and aluminium.

The suitability of the brazing alloys was assessed on the basis of their ability to satisfy four requirements; their brazing temperature should coincide with the annealing and/or hardening temperature of the basis steel; their corrosion- and oxidation-resistance should be comparable with those of the steel; they should cause no embrittlement and/or undercutting of the sandwich foil; they should be self-fluxing. The alloys selected, on that basis, for screening tests are shown below.

Silver-base Alloys
Ag-Li; Ag-Mn-Li; Ag-Cu-Li; Ag-Pd-Mn; Ag-Pt-Ni-Li

Nickel-(Chromium)-base Alloys
'Nicrobraz 10', 'Nicrobraz 50', Nicrobraz 60', 'LC Nicrobraz', 'LM Nicrobraz', 'Coast Metal 50', 'Coast Metal 53'

Nickel-Iron-Phosphorus Alloys
'Coast Metal 608', 'Coast Metal 706', 'Coast Metal 728'

Miscellaneous Alloys
Ni-Pd-Cr-Si; Mn-Ni

In the preliminary evaluation, these alloys were used in combination with the various steels. The compatability of the combinations was determined on thin foil sections and the information so obtained was used in brazing open-faced sandwich structures. Tests on sheet-bend and plate-to-plate shear-compression specimens of the most promising alloy/basis-metal combinations were then made, to determine shear strength and susceptibility to embrittlement.

Based on the results of this exploratory investigation, the brazing alloys shown in the table below were used, in the main phase of the investigation, to fabricate sandwich structures from the steels with which they are correlated in the table.

Basis Steel	Brazing Alloy (All the silver-base alloys were modified with 0·5 per cent. lithium)
'17-7PH'	72-28 Ag-Cu, 93-7 Ag-Cu, 85-15 Ag-Mn, 'CM-53'
'19-9DL'	'CM-50', 'CM-53'
'17-14 Cu-Mo'	'CM53', 75-20-5 Ag-Pd-Mn
Type 422	Ag, 85-15 Ag-Mn, 'CM-50', 'CM-53'
'A-286'	'Nicrobraz 10', 'CM-50', 'CM-53'

The honeycomb panels constructed from the fifteen combinations were subjected to static flexure and edgewise-column-compression tests conducted at room temperature. Three of these combinations were considered structurally suitable for further evaluation by means of similar tests at elevated temperatures and by salt-spray corrosion tests: (1) '17-7 PH' brazed with the 93-7 Ag-Cu alloy and heat-treated to the RH 950 condition; (2) Type 422 steel brazed with the 85-15 Ag-Mn alloy, hardened during brazing and tempered at 800°F. (425°C.); (3) 'A-286' brazed with the nickel-base chromium-silicon-iron-boron alloy 'Coast Metal 53', solution-treated during brazing and aged at 1325°F. (718°C.). Of these three, the third combination gave optimum overall properties and was therefore subjected to bend-fatigue tests at room and elevated temperatures.

The procedures and apparatus used during the investigation are described in detail and the data, which are presented *in extenso*, are liberally supplemented by photomicrographs of the brazed joints. The authors conclude that brazed honeycomb sandwich structures are suitable for use at temperatures up to 1200°F. (650°C.). Their other findings are summarized as follows:

'(1) The basis - metal / brazing - alloy combination '17-7 PH' with 93 Ag-7 Cu modified with lithium may be used satisfactorily for operational temperatures up to 700°F. (370°C.);

'(2) The basis-metal/brazing-alloy combination 422 with 85 Ag-15 Mn modified with lithium may also be used satisfactorily for operational temperatures up to 700°F. (370°C.);

'(3) At operational temperatures up to 1200°F. (650°C.), the optimum sandwich combination is 'A-286' brazed with a nickel-chromium-silicon-iron-boron alloy. At operational temperatures of 1000°F. (540°C.) and above this combination exhibits excellent structural and fatigue properties;

'(4) The basis - metal / brazing - alloy combinations '17-7 PH' with 85 Ag-15 Mn modified with lithium and 422 with 85 Ag-15 Mn modified with lithium are subject to a delaminating type of crevice corrosion when exposed to air or salt-spray atmospheres;

'(5) Satisfactory pre-formed and resistant welded honeycomb core was fabricated from all corrosion-resistant steel alloys used during this investigation, by existing techniques used by the Martin Company (with which the authors are associated);

'(6) Static flexure, edgewise-compression and flexural-fatigue tests provide fairly significant and reliable data on brazed sandwich construction. Core tension and peel tests, at the present time, are not adaptable in obtaining significant test data for brazed sandwich structures. As a complement to existing tests, other methods of elevated-temperature testing should be developed, which will provide additional useful data;

'(7) Research work on brazed honeycomb sandwich structures should be continued, to develop and evaluate base-metal/brazing-alloy combinations for applications above 1200°F. (650°C.) or specifically in the 1500°-1800°F. (815°-980°C.) temperature range.'

See also following two abstracts:

C. F. BURROWS: 'Brazed Steel Honeycomb Structures for 800°F.'

Materials in Design Engineering, 1959, vol. 49, Apr., pp. 110-12.

The article is adapted from a paper presented to the Society of Aircraft Materials and Process Engineers, December 1958. Much of the general information it contains is cognate with that recorded in the report referred to in the preceding abstract; however, the review covers not only the '17-7 PH', 'A-286' and Type 422 steels previously considered as core and skin materials of brazed sandwich structures, but also the following three precipitation-hardenable chromium-nickel steels, which have been studied in the same connexion: 'PH 15-7 Mo', 'AM-350', 'AM-355'.

The article is in four sections. In the first two the author outlines the factors governing selection of basis materials and brazing alloys. Methods suitable for brazing the basis materials are then briefly discussed, and finally reference is made to data indicating typical oxidation-resistance and compression, column-compression, static flexure, flexural-fatigue and stress-corrosion characteristics of honeycomb structures fabricated from some of the steels. Optimum basis - metal / brazing - alloy combinations are listed below.

Parent Metals	Brazing Alloys
'17-7 PH', 'PH 15-7 Mo', 'AM-350', 'AM-355':	Sterling silver modified with 0·2 per cent. lithium; nickel-clad coin silver; 62·5-32·5-5 silver-copper-nickel alloy
Type 422:	Pure silver modified with 0·2 per cent. lithium; nickel-clad coin silver
'A-286':	Acrylic-bonded 'CM53'

F. F. RECHLIN: 'Six Basic Design Rules for Brazed Honeycomb Sandwich.'

ibid., 1959, vol. 49, Mar., pp. 100-5.

This article is of interest in connexion with the subject matter of the two preceding abstracts. Of the six 'basic design rules' considered, the first four are concerned with the design of sandwich structures as affected by brazing considerations: selection of materials with the necessary resistance to structural and dimensional change during fabrication, the necessity of maintaining rigid tolerances to ensure intimate contact between the components, provision of uniform distribution of pressure and temperature, and achievement of the integral shear ties essential for satisfactory brazing. In the last two sections the author discusses factors which affect the brazed honeycomb sandwich as a finished material, i.e., use of cores of varying density, so as to achieve efficient transmission of loads, and the methods by which the sandwich panels may be formed and joined to themselves or to other components, as required by the specific application. The article is well illustrated with diagrams which emphasize the points made in the text.

Production of Structural Parts by Powder Metallurgy: Design Factors

See abstract on p. 169.

Mechanical Properties of Chromium-Manganese-Nickel Austenitic Steels

W. F. EMMONS: 'Evaluation of Chromium-Manganese-Nickel Stainless Steel.'

U.S. Naval Experiment Station, Aeronautical Materials Laboratory Report No. NAMC-AML-AE-1001, Apr. 18, 1956; 4 pp. + figures and tables. Declassified 1958.

The experiments described were carried out to determine the feasibility of replacing steels of 18-8 type used in aeronautical applications by low-nickel high-manganese steels of A.I.S.I. Types 201 and 202. The steel selected for evaluation was of the

following composition: carbon 0·12, silicon 0·46, manganese 7·55, sulphur 0·011, phosphorus 0·009, chromium 16·59, manganese 7·55, nickel 3·93, nitrogen 0·17, per cent.

Specimens of the steel were subjected to (1) stress-rupture tests for 100 hours at 1000°, 1200°, 1300°, 1400° and 1500°F. (540°, 650°, 705°, 760° and 815°C.), (2) tensile tests at room temperature, (3) V-notch Charpy impact tests at room temperature and −65°F. (−54°C.), (4) metallographic examination after exposure at high temperature.

From the data presented it is concluded that the tensile and stress-rupture properties of low-nickel austenitic steel are comparable to those of straight or niobium-containing 18-8 chromium-nickel stainless steels and that the steel is very tough, with no tendency to notch-sensitivity. Prolonged exposure at the elevated temperatures used in the evaluation tests resulted, however, in considerable loss of ductility, due to carbide precipitation.

Physical Properties of Nickel-containing Alloys and Steels

See abstract on p. 170.

Chromium-Nickel-Manganese Steel Bar

AMER. SOC. TESTING MATERIALS: 'Tentative Specifications for Hot-Rolled and Cold-Finished Corrosion-Resisting Chromium-Nickel-Manganese Steel Bars.'

A.S.T.M. Designation A 429-58*T*.

A.S.T.M. Standards, 1958, Pt. I, pp. 805-9.

The specification covers rounds and hexagons, squares or shapes, also ground and ground-and-polished rounds, in material to the limits of composition shown in the table below.

Magnetic Permeability of Chromium-Manganese-Nickel Steels

M. R. GROSS: 'Investigation of the Normal Magnetic Permeability of A.I.S.I. Type 201 and 202 Steels.'

U.S. Naval Engineering Experiment Station, Annapolis, Report 040095; *NSM*-013-126, Jan. 9, 1957; recently declassified; 4 pp.

The materials examined were steels to the A.S.T.M. specifications for A.I.S.I. Types 201 and 202; comparison was made with counterparts of these steels in the Type 300 series. Magnetic permeability was determined in the as-received condition and after cold-rolling to 10, 20 or 30 per cent. reduction. The magnetic permeabilities of the two high-manganese steels were found to be closely similar to those of the corresponding '18-8' chromium-nickel steels.

It is recommended that Type 201 should not be used, except possibly in the fully annealed condition, in applications calling for non-magnetic characteristics. (It is noted that Type 301 also is not included in materials listed as suitable for such applications. Both 201 and 301 compositions are selected to give high structural strength under mildly corrosive conditions, but, in order to develop such high strength, it is necessary to cold-work the steels, which transforms the non-magnetic austenite of the annealed condition into pseudo-martensite, a transformation which is associated with potentially high and variable permeability, as compared with the value of 2·0 required by the U.S. Navy in material for non-magnetic applications.)

Type 202 steel is considered to be suitable for inclusion in the list of steels for such uses, as covered by specification *MIL-N*-17387*A* (*SHIPS*).

Wear- and Galling-Resistant Nickel-Copper-Silicon Alloys

See abstract on p. 180.

Solubility of Hydrogen in Niobium-Stabilized Stainless Steels

R. BLANCHARD: 'Solubility of Hydrogen in Stainless Steels.'

Comptes Rendus, 1959, vol. 248, Feb. 16, pp. 966-8.

Data on the solubility of hydrogen in a niobium-stabilized chromium-nickel stainless steel over the temperature range 300°-600°C. were reported by ARMBRUSTER in 1943 (*Jnl. Amer. Chemical Soc.*, vol. 65, pp. 1043-50). HAWKINS determined similar data for temperatures up to 750°C. (see *U.S. Atomic Energy Commission*, 1953, *Report KAPL* 868). In this latest communication solubility data are presented for the remaining temperature range up to 1000°C. In addition, reference is made to findings with respect to the influence, on hydrogen solubility, of the niobium and molybdenum contents of the three 18-8 type chromium-nickel steels considered.

The average values for hydrogen solubility vary, per 100 g., from 5·3 cm.^{3} at 700°C. to 7·25 cm.^{3} at 1000°C. The presence of molybdenum and niobium slightly decreases solubility over the temperature range studied. At elevated temperatures, the influence of niobium in this respect is greater than in the lower ranges.

Steels to A.S.T.M. Designation A 429-58T

C %	Si %	Mn %	S %	P %	Cr %	Ni %	N_2 %
0·15 max.	1·00 max.	5·50-7·50	0·030 max.	0·060 max.	16·00-18·00	3·50-5·50	0·25 max.
0·15 max.	1·00 max.	7·50-10·00	0·030 max.	0·060 max.	17·00-19·00	4·00-6·00	0·25 max.

Resistance of Aluminium-containing Nickel-base Alloys to Oil-Ash Corrosion

J. F. KELLY: 'Fuel-Oil-Ash Corrosion-Resistance of Aluminium-bearing Nickel-base Alloys.'

U.S. Bureau of Ships, Report R-229, Apr. 24, 1957; 5 pp. + figures. *P.B.* 134675.

The investigation described in the report formed part of a programme planned with the aim of developing materials having higher resistance to attack by fuel-oil ash than that exhibited by the 25-20 chromium-nickel steel normally used for certain non-structural parts of Naval boilers.

The evaluation tests reported were carried out on a nickel-base alloy of the following composition: carbon 0·15, chromium 15, molybdenum 5, iron 5, boron 0·15, per cent.; remainder nickel. To this basis alloy aluminium was added in the following amounts: 0·79, 0·89, 1·96, 2·48, 5·94, 7·21, 8·54 or 9·56, per cent. Control specimens of 25-20 chromium-nickel stainless steel were included in the test programme. The corrodents used

10 g. of 15% Na_2SO_4: 85% V_2O_5;

14·3 g. of 63% Na_2SO_4: 7% V_2O_5: 30% carbon;

10 g. of 24·6% $NaVO_3$: 75·4% V_2O_5;

were intended to represent, respectively, high-vanadium, high-sodium/carbon-bearing, and high-vanadium/sulphur-free oil ash. The test involved partial immersion in the corrodent for 5 hours at 1700°F. (925°C.).

The corrosion behaviour of the alloys was similar to that of the chromium-nickel steel. In the high-vanadium corrodents the surface of the specimens remained smooth and uniform: in the other corrodent, attack was more localized and in some cases pitting occurred.

The nickel-base alloy *per se* was found to be more susceptible to attack than the stainless steel. Aluminium at about 1, 2 and 2½ per cent. had no beneficial effect in this respect, but the corrosion-resistance of specimens containing higher (7, 8 and 9½) percentages of aluminium almost equalled that of the 25-20 chromium-nickel steel. The nickel-base alloys containing 6 per cent. aluminium exhibited a higher resistance to attack: weight-loss was only half that of the control steel specimens. In general, the resistance of the nickel-base alloys did not differ significantly in any of the three corrodents used.

It is recommended that in future investigations the range of aluminium contents studied should be limited to 2½-7 per cent.

Preparation of Metallographic Specimens

See abstract on p. 171.

Identification of Corrosion Products on Copper Alloys

NAT. ASSOCN. CORROSION ENGINEERS: 'Identification of Corrosion Products on Copper and Copper Alloys.' Report of N.A.C.E. Tech. Unit Committee T-3B on Corrosion Products.

Corrosion, 1959, vol. 15, Apr., pp. 199t-201t.

The report opens with a review of the nature of the corrosion products normally found on copper or copper alloys which have been subjected to atmospheric exposure or to fresh or sea water. For determination of the nature of the corrosion products, microchemical analytical methods are most useful, especially when only a small sample is available. The metallic components of the corrosion products can be quickly determined also by emission spectrographic analysis, but this method does not provide for identification of the compounds present.

This report gives detailed recommendations for microchemical examination and identification of both soluble and insoluble constituents; procedures for identification of oxides, chlorides, sulphates, sulphides, carbonates, silica, calcium, magnesium, sodium, ammonia and metal constituents are included. Spectrographic technique is more briefly considered.

Determination of Titanium, Zirconium, Niobium and Tantalum in Steels

See abstract on p. 185.

Sub-Zero Properties of Austenitic Chromium-Nickel Steels

R. H. KROPSCHOT and W. F. GRAHAM: 'Mechanical Properties of the Austenitic Stainless Steels at Low Temperatures.'

Nat. Bur. Standards Report 5009; *Tech. Memorandum* 39; Aug. 30, 1956; recently declassified; 6 pp.+ 32 figs. and tables.

The report embodies results of tests made at the Bureau of Standards, correlated with data in the literature. It contains information on straight chromium-nickel steels of '18-8' and higher-alloy types, and of austenitic chromium-nickel steels containing titanium, niobium and molybdenum in various proportions.

The properties covered include chemical composition, tensile and yield strength, elongation, reduction of area, Young's modulus, impact strength, welding properties, effect of sensitization and sigma formation, and hardness after various amounts of cold work. The N.B.S. results, which are stated to agree well with those obtained by other investigators, extend the range to a lower temperature than that for which data had previously been available, i.e., to 20°K. (−253°C.). Reference to earlier literature is given in a *bibliography* of 24 items.

The information obtained from the combined sources shows that:

(1) Tensile strength increases with fall in temperature: the increase is greater for annealed than for cold-worked materials.

(2) With one exception, the values obtained in the Bureau of Standards tests show a slight increase in yield strength (0·002 per cent. offset) with fall in temperature, but it is noted that other observers have reported both increase and decrease. It is considered that low-temperature design stresses

cannot be greatly increased over those used for normal-temperature use, because the yield strength remains so nearly constant, but the factor of safety to ultimate failure increases at sub-zero temperatures, due to the increase in tensile strength.

(3) Elongation and reduction of area tend to decrease with fall in temperature, but even at 20°K. (−253°C.) and below, tensile failures still exhibit some ductility.

(4) Modulus of elasticity in tension increases as the temperature is lowered: data from various sources show an increase of 5–15 per cent. at 77°K. (−196°C.).

(5) Impact strength decreases with fall in temperature, but, except in sensitized or sigma-containing material, notch-toughness at 20° and 77°K. (−253° and −196°C.) is still above the A.S.T.M. minimum specification value.

(6) Data on the effect of low temperature on fatigue properties are relatively sparse, but the indication is that endurance limit, for both notched and unnotched specimens, increases with fall in temperature.

(7) Welding techniques now available are capable of producing joints having tensile and impact properties satisfactory for low-temperature service, but care must be exercised to avoid sensitization, sigma formation and crater cracking.

Nickel-containing Steels for Low-Temperature Applications in the Petroleum Industry

E. T. GILL and G. L. SWALES: 'Nickel-containing Steels for Low-Temperature Applications in the Petroleum Industry.'

Brit. Petroleum Equipment News, 1959, vol. 7, Spring, pp. 60–4.

In the course of their review the authors allude to criteria governing the selection of steels for low-temperature applications and make the point, in connexion with a discussion of brittle fracture, that nickel is the alloying element most effective in conferring improved low-temperature properties, especially toughness, on wrought and cast ferritic steels. Advantage has been taken of this characteristic in a series of nickel-containing steels which cover the range of working temperatures down to −196°C. Such steels are finding increasing application in the petrochemical field, and future developments in the bulk transportation, at sub-zero temperatures, of liquefied natural and petroleum gases are expected to widen their application. The present paper is concerned with the low-temperature characteristics of five grades of steel: 2½, 3½, 5 and 9 per cent. nickel steels and the chromium-nickel austenitic steels.

The review is in two sections. In the first the authors indicate the characteristics which render a steel suitable for sub-zero applications, and refer to the notched-bar impact tests by which low-temperature properties are assessed. A valuable feature of the section is a table in which are summarized the A.S.M.E., A.S.T.M., and B.S. specifications covering various forms of the five grades of steel used for low-temperature applications.

Emphasis is placed upon the importance of selecting materials appropriate to the specific operating temperature range. Broadly speaking, fully-killed carbon-manganese steels cater for temperatures down to −50°C., 2½ per cent. nickel steel down to −60°C., 3½ per cent. nickel steel down to −100°C., and 9 per cent. nickel or austenitic chromium-nickel steels for lower temperatures. Choice of a steel for the lowest temperature range (−100° to −200°C.) offers the alternatives of the 9 per cent. nickel or the austenitic chromium-nickel steels. Steels of the latter type have the advantage of not exhibiting a definite transition-temperature range, but they are significantly more expensive than the 9 per cent. nickel steel and their tensile properties are somewhat lower. The 9 per cent. nickel grade was specially developed to meet the need for a material suitable for this very low range of temperature.

The second part of the paper comprises a review of the low-temperature characteristics of the 3½ and 9 per cent. nickel and austenitic chromium-nickel steels in wrought, welded and (with the exception of the 9 per cent. nickel steel) cast forms. Relatively little information has been published on the low-temperature properties of the austenitic steels in cast form, but mention is made in the paper of recent work relevant in this respect, carried out in the laboratories of The Mond Nickel Company. The results of this work have now been reported in detail: *see following abstract.*

Low-Temperature Properties of Cast Austenitic Steels

G. MAYER and K. BALAJIVA: 'The Low-Temperature Mechanical Properties of Some Cast Stainless Steels.'

Metallurgia, 1959, vol. 59, May, pp. 221–6.

The aim of the investigation described was to obtain comparative data on the tensile and impact properties of a range of 18-8-type chromium-nickel cast steels at sub-zero temperatures. Nine steels, with carbon contents varying from 0·055 to 0·14 per cent., were selected for investigation. The tests were carried out mainly on laboratory heats, but the impact properties of two commercially-produced test castings were also examined. Several of the steels were stabilized with niobium and one with titanium.

Tensile test pieces and Charpy V-notch specimens were machined from four-leaf-clover test blocks, in which all but one of the laboratory heats were cast. The exception, which was of low-carbon type, was cast in keel blocks, from which only Charpy V-notch specimens were machined. The castings were annealed at 1050°C. and water-quenched before machining. Tensile properties were determined at 20°, −78° and −196°C., and the impact tests were carried out over the temperature range +100° to −196°C. Discussion of the results of metallographic examination of the steels is supplemented by micrographs.

The conclusions drawn from the data presented are summarized as follows:

'Cast 18-8-type chromium-nickel steels containing 0·1 to 0·14 per cent. of carbon provide, in the annealed condition, a useful combination of tensile and impact properties for low-temperature applications. At room temperature, maximum-stress values of about 33 t.s.i. (52 kg./mm.^{2}), an elongation of 50 to 60 per cent. and Charpy V-notch impact values of 90 to 120 ft.-lb. (12·4-16·5 kgm.) are obtainable. At −196°C. ductility remains relatively high (in the region of 10 per cent.) and impact values of 20 to 45 ft.-lb. (2·7-6·2 kgm.) may be expected. The low-temperature impact properties are improved if the carbon content is maintained at a relatively low level, values of about 70 ft.-lb. (9·6 kgm.) being obtained at −196°C. for steels containing 0·05 to 0·06 per cent. carbon.

'Stabilized cast stainless steels with a content of about 0·1 per cent. carbon give tensile properties similar to those of the non-stabilized steels, but impact values are lower at room temperature. Impact properties, however, are again improved if the carbon content, and the corresponding stabilizing additions, are reduced. Thus, in steels of the 18-10 chromium-nickel-niobium type containing 0·05 to 0·06 per cent. carbon values of about 40 and 70 ft.-lb. (5·5 and 9·6 kgm.) are obtained at, respectively, −196° and −20°C.'

Steels for Use with Concentrated Hydrogen Peroxide: Specification

MINISTRY OF DEFENCE: 'Selection and Treatment of Corrosion-Resisting Steels for Use with Concentrated Hydrogen Peroxide (H.T.P.).'

Defence Specification DEF-61, Nov. 13, 1958; 3 pp. Published by *H.M. Stationery Office*, London. Price 2/-.

The specification relates to the selection of steels for the surfaces of equipment used in contact with H.T.P. (high-test peroxide) liquid and its associated vapour, up to the region in the equipment where decomposition becomes acceptable. The schedule is in four sections: in the first reference is made to related specifications: the second, which gives guidance on selection of materials, includes a table indicating the suitability, for service with H.T.P., at 20°-25°C. and 40°C. and for various times, of steels of austenitic chromium-nickel, high-chromium low-nickel, and high-chromium types. Sections 3 and 4 lay down precautions to be taken during fabrication of the steels (cleanness, forming and welding) and surface treatment of the fabricated parts.

An appendix gives details of pickling solutions suitable for use with austenitic steels.

Corrosion-Resistance of Automobile Components

L. C. ROWE: 'Automotive Corrosion-Resistance: Past and Present.'

Corrosion, 1959, vol. 15, Apr., p. 167t.

This short note, selected as the 'Topic of the Month' in *Corrosion*, is of particular interest in relation to the recent paper by DU ROSE and PIERCE (*Metal Finishing*, 1959, vol. 57, Mar., pp. 44-50, 54; see abstract in *Nickel Bulletin*, 1959, vol. 32, No. 4, pp. 146-7). Some of the facts and opinions given by the author are excerpted below, for comparison with the conclusions drawn by Du Rose and Pierce.

'Direct comparison of corrosion-resistance between the automobile of yesteryear and that of to-day is obviously impossible. Statistics* tend to support the theory that the modern automobile has more built-in protection than its old-time counterpart. In 1925 the life of the automobile was 6½ years and had a total mileage of 25,740 miles. In 1950 these figures were increased to 12¼ years and 103,000 miles. Corrosion-resistance was definitely a supporting factor in obtaining this increased service.

'This is the more significant when one considers that this durability has been attained in spite of a gradual intensifying of corrosive conditions. Increased industrial manufacturing has led to a large output of contaminants into the atmosphere. This, in combination with other materials, has produced an environment which is more corrosive in nature. Further, since 1930 there has been an increase of 135 per cent. in registered vehicles, which has brought in its train a change in driver habits and in road conditions. A smaller percentage of cars is being maintained in garages or shelters, there is more high-speed travel and exposure to variable conditions, and more short trips of the type in which the most corrosive residues are produced.

'One can only conclude that conditions are much more corrosive than they were formerly, and it can be presumed that the good old car of the past would fare rather badly under present conditions.

'Car structure as a whole has been improved through the use of more durable materials. Part of this advance is due to the development of new materials, and part to improved machining and surface finishing. Metallurgical research has been responsible for improved techniques in casting and metal working.

'Corrosion of automotive trim and plated parts has resulted in some criticism in later years. Actually, the total plated film is equivalent to, or greater in thickness than, that previously used. Failures which show up are due to more corrosive conditions, difficulty in obtaining a uniform coating due to design, quantity production, and lack of maintenance by the owner. Brighter things are in store, due to the vast increase in technical knowledge. Through the use of new control tests, production standards should be better.

'Many advances have been made by the manufacturer in corrosion protection, but a good share of the responsibility remains with the customer. By proper maintenance and frequent washings to remove corrosive substances, the car owner can increase the effectiveness of the preventive measures taken by the manufacturer.'

*The statistics quoted by the author are based on U.S. sources of information.

Applications of High-Nickel Alloys in the Petroleum Industry

G. L. SWALES: 'Some Applications of High-Nickel Alloys in the Petroleum Industry.'
MOND NICKEL CO., LTD., *Publn.* 1602; 19 pp.
Reprint from *Petroleum*, 1958, vol. 21, Nov., pp. 391–4; Dec., pp. 439–43.

See abstract in *Nickel Bulletin*, 1959, vol. 32, No. 2, pp. 59–60.

Stainless Steel in Surgical Equipment

'Stainless Heat Exchanger for Heart Surgery.'
Materials in Design Engineering, 1959, vol. 49, Apr., p. 7.

A heat exchanger consisting of thin-walled stainless-steel tubing having an especially smooth finish on the interior surface is being used to lower blood temperature in delicate open-heart surgery. The unit is mounted between a heart-lung machine and the patient. The blood is cooled (and warmed after the operation) by a parallel flow of water in the surrounding jacket. The 24 tubes of the exchanger are made of low-carbon 18-8 stainless steel, a material selected because it is completely resistant to chemicals present in the blood, is capable of taking an extremely smooth surface finish, and can be fabricated to very close tolerances. Each of the 15·1-in. (37·75-cm.) long tubes has a 0·210-in. (5·25-mm.) outside diameter, a 0·020-in. (0·5-mm.) wall, and an o.d. tolerance of +0·000, −0·001-in. (−0·025-mm.).

American Developments in Investment-Cast Materials

See abstract on p. 170.

Non-Ferrous Alloys in Marine Engineering in the U.S.A.

See abstract on p. 178.

Fabrication and Design of Nickel-Alloy Pipe and Tube

See abstract on p. 181.

'Monel' Roofing: Data Sheet

See abstract on p. 181.

Spring Materials: Specifications and Design Factors

See abstract on p. 170.

Machining of High-Nickel Alloys

See abstract on p. 181.

The 'Sprayweld' Process and Its Applications

W. J. BURLING SMITH: 'The Colmonoy 'Sprayweld' Process and its Applications.'
Welding and Metal Fabrication, 1959, vol. 27, Feb., pp. 54–60.

Much use has been made of conventional metal-spraying processes in 'building up' and reclaiming worn engineering components. When, however, the component is intended for service under conditions involving high stress, the success of such techniques must be assessed in terms of the porosity and adhesion of the deposit and the presence of internal stress. On the basis of these criteria, conventional sprayed-metal deposits are in many cases unsatisfactory.

Research carried out with the aim of devising a technique which would combine the ease and control of metal-spraying techniques with the excellent mechanical properties and adherence of deposits produced by normal welding methods resulted in development of the Colmonoy 'Sprayweld' process. This process involves spraying a powdered nickel-chromium-boron-base 'Colmonoy' alloy onto the surface of the component and then fusing it by exposure to heat from a torch or furnace, a procedure which produces a smooth, non-porous hard facing, accurate to within 0·01 in. (0·25 mm.) of finished dimensions. The 'Sprayweld' process and its applications are reviewed in the present paper.

A description of the procedure used for surface preparation before 'Spraywelding' is followed by details of the precautions necessary during spraying, and by a discussion of the three methods used to fuse the 'Colmonoy' overlay: use of an oxy-acetylene torch, heating in a controlled-atmosphere furnace, and induction heating. The author then outlines the procedures employed to 'Sprayweld' over a 'Sprayweld' deposit and to machine and grind the coatings.

The final section of the paper is concerned with the industrial applications of the process. This review is introduced by a résumé of the metallurgical characteristics and corrosion-resistance (to specific corrosive media) of the 'Colmonoy' alloys. In general, the process is of value in application to such units as pump rams or sleeves operating under severe service conditions, shafts and rams showing rapid wear, valve plugs and seats which require frequent renewal, guides and wear plates. Relevant factors which are considered in this connexion are the material and design of the component concerned, and the precise service conditions. Typical compositions, physical properties and service characteristics of Alloys 4, 5, 6 and 70 of the 'Colmonoy' series are included in the paper, together with a table indicating materials suitable for hard-surfacing by the 'Sprayweld' process.

Brazing of High-Temperature Alloys: New Brazing Alloys

E. V. BEATSON: 'The Contribution of Brazing in Light Engineering. Design and Process Selection.'
Sheet Metal Industries, 1959, vol. 36, Mar., pp. 191–200.

Paper presented at Conference on Technology of Engineering Manufacture organized by the Institution of Mechanical Engineers in London, March 1958.

The years immediately following the Second World War have witnessed important advances in welding and brazing, as in other fabrication techniques. The impetus has come, to a significant degree, from the development of new industries in which the specification requirements for welded and brazed joints have become increasingly stringent, and such requirements have been supported by growing competition and a general accent on maximum efficiency and productivity.

This paper contains a review of some of the major developments in brazing technique and materials, with special reference to methods suitable for production of brazed joints in corrosion- and heat-resisting materials. The author opens with a discussion of the factors influencing selection of the joining processes to be used for specific applications, emphasizing the importance of making a choice at the design stage, so that all details of form, material, processing, etc., may be controlled to ensure emergence of a satisfactory component, with minimum cost, trouble-free production, and maximum serviceability. Factors which call for such initial consideration are discussed by reference to typical brazed parts.

Research and development in this field have recently centred mainly on the brazing of heat- and corrosion-resisting materials and some of the newer engineering metals, e.g., titanium, molybdenum, zirconium and tantalum. The work done has been chiefly in two general directions:

(1) Development of new brazing alloys, to provide improved strength and other properties in the joint, particularly at the high temperatures at which the brazed parts will operate.

(2) Development of brazing techniques which will reduce or remove, preferably without the use of flux, the extremely tenacious oxides encountered on the high-temperature alloys, so that 'wetting' by the brazing alloy can be satisfactorily accomplished.

Some of the achievements which have resulted from this work are reviewed by the author, as exemplified by brazing techniques developed for use on nickel-chromium-base alloys and stainless steels. The various methods which can be used, and the suitability of the respective processes for individual applications, are considered, with illustrations. Brazing in a hydrogen or hydrogen/nitrogen atmosphere and vacuum brazing are thus discussed, and attention is directed also to applications in which high-frequency induction brazing, resistance brazing, or other specialized techniques may be employed.

In discussion, E. R. PERRY commented on the following points:

(1) The problem of metal cracking due to penetration of liquid brazing alloy into the surface of the base metal during brazing, with resultant embrittlement. Data presented demonstrate that there is a tendency for embrittlement to be less severe with brazing metals the melting points of which are higher than those of the conventional silver solders.

(2) The deleterious effect of boron in brazing alloys. Records relating to the intercrystalline penetration of an alloy of the 'Nimonic' series by a nickel-chromium-boron brazing alloy showed the harmful effect of the hard boride phase on the mechanical properties of the brazed joint.

(3) Development, by The Mond Nickel Company, of a range of palladium-containing brazing alloys which are found to be free from the disadvantages mentioned above. It has been observed that the addition of palladium to some of the usual filler alloys (copper, copper-silver eutectic and 85–15 silver-manganese alloys,) is accompanied by marked improvement in brazability, corrosion-resistance and strength of joint. Based on these observations, a range of palladium-containing alloys has been developed for joining nickel-base alloys both to nickel alloys and to other materials such as cupro-nickels, cobalt-base alloys, steels, beryllium, gold, copper, molybdenum, tungsten and other metals. (Typical compositions, melting ranges and brazing temperatures were quoted for silver-palladium-manganese, nickel - manganese - palladium, copper - palladium - silver and nickel-palladium alloys, and reference was made to applications for which the respective types are particularly suitable.) Attention was drawn to the good flowability and wetting characteristics of the palladium-containing alloys, to the fact that they impose only slight attack on the steels or alloys joined, and to their ductility. The advantages gained by the use of alloys of this new series were emphasized.

Development of Brazing Alloys for Joining 'Zircaloy' Components of Pressurized Water Reactors

R. E. DROEGKAMP: 'Development of Brazing Materials for Joining 'Zircaloy'.'
Bettis Tech. Rev., Reactor Metallurgy, WAPD-BT-10, Oct., 1958, pp. 9–13.

The paper gives details of preliminary screening tests conducted at Armour Research Foundation with the aim of developing brazing materials suitable for joining zirconium-base alloys of 'Zircaloy' type, intended for service in pressurized-water reactors.

The alloys tested were of the following types:

Ag-Cu, -Cu-Si, -Cu-Sn, -Cu-In, -Mn, -In
Al-Ni, -Be, -Si, -Pd, -Ge, -Ge-'Zircaloy 2'*
Au-Co, -Be
Cu-P, -Ag-P-Sn, -Pd-In, -Be
Ni-Ge-Cr, -Pd-Si, -Cr-Si
Pd-Si, -Nb, -Sn

In addition, tests were made with alloys based on 'Zircaloy 2' (and containing Cu, Ni, Ni+Sn, Be, Fe+Sn, or Fe+Mn), with 'Kanigen' nickel-phosphorus deposits, with aluminium coatings and silver. The suitability of the brazing materials was to be assessed on the basis of three criteria: (1) brazing characteristics, and properties of the joints, (2) resistance to attack by pressurized water under high-temperature conditions, (3) satisfactory performance under irradiation.

Each of the materials investigated was used to braze specimens of 'Zircaloy 2' and 'Zircaloy 3'† The brazed specimens were subjected to metallographic examination and to screening tests in pressurized distilled water at 680°F. (360°C.) for 1200 hours (or until failure occurred). Some work was also done to compare flow properties as a function of time and brazing temperature.

Four of the materials studied produced joints which withstood the high-temperature corrosion test: a 'Zircaloy 2'-base alloy containing 4 wt. per cent. of beryllium; the nickel-phosphorus ('Kanigen') deposit; a 70-20-10 nickel-palladium-silicon alloy; and a 77-20-3 copper-palladium-indium alloy. Of these, the 'Zircaloy 2'-base alloy exhibited the best flow properties, and gave the strongest and most corrosion-resistant joints. The 'Kanigen' alloy has the advantage of being pre-placed by plating, but only the copper-palladium-indium alloy could be fabricated by conventional forging and rolling methods.

In connexion with this investigation, attention may be directed to work, by MCANDREW, NECHELES and SCHWARTBART, on the brazing of 'Zircaloy' to austenitic stainless steel (*Welding Jnl.*, 1958, vol. 37, Dec., pp. 529s-34s: see *Nickel Bulletin*, 1959, vol. 32, No. 2, p. 61).

Hydrogen Brazing of High-Temperature Alloys

G. S. HOPPIN and E. N. BAMBERGER: 'Effects of Hydrogen Brazing on Properties of High-Temperature Alloys.'

Welding Jnl., 1959, vol. 38, Apr., pp. 194s-201s.

Brazed assemblies of thin sheet of high-temperature materials are being increasingly used to secure the ultra-light-weight, high-strength components required in construction of supersonic and other aircraft components. For parts which will operate at temperatures up to about 800°F. (425°C.) silver brazing is satisfactory, but for service at higher temperatures this method of joining cannot be used, due to the low strength and poor oxidation-resistance of the silver alloys. For the higher-temperature range nickel-base brazing materials are being successfully employed, but these materials present certain characteristics which require consideration if sound, serviceable joints are to be obtained. One of the problems involved relates to the filler materials themselves, which are all relatively brittle, and also tend to 'erode' (or dissolve) the thin sheet-metal base at the temperatures used in brazing (usually above 2000°F. (1095°C.)). Procedures have, however, been developed to minimize difficulties arising from that source. A further problem in this connexion is independent of the filler materials, but is due to the effect, on the basis material, of exposure to the high temperatures required for brazing. To minimize distortion, virtually all brazing of aircraft-engine sheet-metal assemblies is done in hydrogen-atmosphere furnaces, but the time at high temperature inevitably involved, especially for large components, is considerable.

So long as parts brazed at these high temperatures were not heavily loaded in subsequent service no trouble arose, and little attention was paid to the effect of brazing temperature on the properties of the parent materials, but tests made in the laboratory of General Electric Company, on a large 'Inconel' component which had been brazed with a nickel-base filler metal in a cycle involving a temperature of 2150°F. (1175 °C.) indicated that the brazing conditions had seriously impaired the yield strength of the 'Inconel'. The deterioration was confirmed by comparative tests on 'Inconel' sheet which had undergone the normal annealing cycle. Exposure to the brazing temperatures (up to 350F°. : 195C°. above the normal annealing range for 'Inconel') had resulted in excessive grain growth, associated with loss in mechanical strength.

These observations led to initiation of a series of investigations to determine the effects produced, on typical high-temperature alloys, of high-temperature hydrogen-atmosphere cycles necessarily used in brazing with nickel-base filler metals. The materials selected were chosen as being types currently used in brazed jet-engine components and/or likely to be so used in the foreseeable future. Compositions are shown in Table I, p. 201.

These materials represent five groups: non-heat-treatable austenitic stainless steel (Type 310); heat-treatable martensitic stainless steel (Type 410); age-hardening stainless steel ('17-7 PH'); age-hardenable 'super-alloys' ('A-286', iron-base; 'Inconel 702', nickel-base; 'René 41' nickel-base; 'J-1570', cobalt-base) and non-age-hardenable 'super-alloy' ('L-605', cobalt-base). Specimens of sheet material of these compositions were subjected to two heat-treatments: (1) that normal for the particular alloy, or (2) a hydrogen-atmosphere furnace-brazing cycle involving a maximum temperature of 2240°F. (1226°C.). In the case of the hardenable materials a full heat-treatment was given to one set of samples which had gone through the brazing cycle, in order to ascertain to what extent properties deleteriously affected by brazing were recoverable.

Stress-rupture characteristics, at various temperatures, and tensile properties before brazing, after

* Sn 1·5, Fe 0·12, Cr 0·10, Ni 0·05, per cent., bal. Zr.
† Sn 0·25, Fe 0·25, per cent., bal. Zr.

Table 1

Nominal Chemical Compositions of Sheet Alloys Exposed to Temperatures Involved in Brazing

Alloy	Element									
	C %	Ni %	Cr %	Mo %	Co %	W %	Ti %	Al %	Fe %	Other Elements %
Type 410	0·15 max.	0·50 max.	12·5	—	—	—	—	—	Bal.	Mn 1·00 max. Si 1·00 max.
Type 310	0·10	20	25	—	—	—	—	—	Bal.	
'17-7 PH'	0·07	7	17	—	—	—	—	1·10	Bal.	
'A-286'	0·05	26	15	1	—	—	2·0	0·2	Bal.	V 0·3
'Inconel 702' ..	0·02	Bal.	15	—	—	—	0·5	3·0	0·35	
'J-1570'	0·20	30	30	—	Bal.	6·5	4·1	—	—	
'René 41'	0·16	Bal.	19·3	9·4	9·5	—	3·2	1·9	2·8	
'L-605'	0·10	10	19·5	—	Bal.	14·5	—	—	2·5	B 0·04

brazing and, in the selected materials, after brazing + ageing, are reported *in extenso*, together with observations on the structural changes produced by the brazing operation.

The results show that the strength losses and microstructural changes varied from one material to another. The alloys which are normally strongest at high temperature ('René 41', 'L-605' and 'J-1570') were least affected by the severe brazing cycle used. The losses suffered by 'René 41' could largely be recovered by complete re-heat-treatment, and the other two were but little harmed except for room-temperature embrittlement. Type 310 steel and 'Inconel 702' suffered the greatest loss in strength. In 'A-286' there was a moderate fall in strength after the brazing cycle, but re-heat-treatment restored most of the loss.

The authors suggest that some rationalization of the effects of brazing cycles may be made on the basis of the strengthening mechanisms operating in the respective alloys. The strength levels of the weakest materials are dependent primarily on fine grain-size resulting from mechanical working in the mill. The strongest alloys, on the other hand, derive most of their strength from complex, finely divided precipitated particles. The grain-size changes resulting from the brazing cycle therefore have the greatest effect on the weakest alloys, whereas the strongly age-hardenable materials are affected only to the degree that their strength is influenced by a fine grain-size and optimum precipitate dispersion resulting from a given solution temperature, and the latter portion of the strength-loss due to the brazing cycle can be regained by complete re-heat-treatment. In many cases, however, it may not be possible completely to re-treat an age-hardenable material after brazing, and in such cases only the strength available by ageing after brazing can be utilized. It is pointed out by the authors that: '17-7 PH' and Type 410 steel differ with regard to the strengthening mechanism operative. Loss of strength in the chromium steel by methane reaction on decarburization (C (alloy + $2H_2$) (brazing atmosphere)$\rightarrow CH_4$) appears to account for the time-dependent loss of strength observed in this alloy when brazed, but the loss of strength for '17-7 PH' cannot be so easily explained. This complex material depends on both the martensite reaction and on precipitation hardening for its strength, and either decarburization or non-optimum distribution of precipitate due to exposure to the brazing cycle could cause loss in strength.

It is considered that the greatest significance of the work reported is the collection thereby of data which have proved conclusively that hydrogen brazing at very high temperatures detrimentally affects the strength of high-temperature alloys and that the damage varies in degree in relation to the composition of the alloys.

Wetting Reactions in Brazing of High-Temperature Alloys

W. FEDUSKA: 'High-Temperature Brazing-Alloy/Base-Metal Wetting Reactions.'
Welding Jnl., 1959, vol. 38, Mar., pp. 122s-31s.

The paper reports one stage of a series of fundamental investigations undertaken by Westinghouse Electric Corporation with the aim of obtaining a clearer understanding of the factors controlling formation of brazed joints in materials intended for service at temperatures up to about 1800°F. (980°C.). Details of another phase of the same research programme (concerned with study of microstructural and hardness characteristics of a variety of high-temperature brazing-alloy/base-metal interfaces) have been given in a previous paper (*ibid.*, 1958, vol. 37,

Alloy	Composition of Brazing Alloys												Normal Brazing Temp.		Superheat Brazing Temp.	
	C	Si	Mn	Cr	Ni	B	S	P	Zr	Ag	Al	Fe				
	%	%	%	%	%	%	%	%	%	%	%	%	°F.	°C.	°F.	°C.
1	0·76	4·60	—	13·67	Bal.	3·13	—	—	—	—	—	4·29	1980	1080	2055	1123
2	0·80	4·00	—	15·00	Bal.	4·00	—	—	—	—	—	4·00	1960	1069	2050	1120
3	0·17	9·91	0·81	18·95	Bal.	—	0·005	0·005	0·03	—	0·08	0·49	2120	1160	2210	1209
4	0·03	11·25	—	19·00	Bal.	—	—	—	—	—	—	1·10	2160	1182	2250	1231
5	—	—	15·00	—	—	—	—	—	—	85·0	—	—	1850	1008	1940	1058
6	—	4·58	—	—	Bal.	2·89	—	—	—	—	—	—	2070	1131	2160	1182

Feb., pp. 62s–73s; abstract in *Nickel Bulletin*, 1958, vol. 31, No. 6, pp. 177–9). In both phases of the investigation the same materials were used as basis metals: a chromium martensitic stainless steel, a chromium–nickel austenitic steel, and three heat-resisting alloys, respectively of nickel, cobalt and iron base. (The compositions of the base materials were tabulated in *The Nickel Bulletin* as part of the abstract of the previous paper.)

Of the six brazing alloys employed in the experiments now described, alloys 1, 3, 4 and 6 were used also in the microstructural studies: compositions of all six alloys are shown, together with brazing temperatures, in the table above.

The wettability tests were conducted at nominal or superheat brazing temperature, the specimens being heated to temperature in about 2 minutes, held at temperature for 1 minute, and then cooled to 400°F. (205°C.) in about 20 minutes, before removal from the apparatus. Tests at superheat temperature were conducted either *in vacuo* or in an atmosphere of dry hydrogen; tests at nominal brazing temperatures were carried out also in a dry-helium environment. In all, some 118 combinations of basis metals, brazing alloys and protective environments were studied. The surface area covered by the brazing alloys was measured by tracing the boundaries on actual-size photographs of the wettability specimens: photographs of transverse microsections through the brazing-alloy/basis-metal interface were used to determine solidified contact angles between brazing alloy and the basis metal. Data on wetted area, contact angle and 'wetting index' (which indicates relative wettability) are tabulated for each test combination, and the paper includes photographs illustrating wettability and the contact angles obtained. Factors which control wettability are discussed.

The author's overall findings are summarized as follows:

'*Wetting Reactions at Nominal Brazing Temperature*

'(1) By considering only those wettability tests which produced a satisfactory result (wetting index = 0·2, or greater), the following 'behaviourisms' were found:

(*a*) Of the base metals, the cobalt-base alloy was most readily wetted by the brazing alloys, followed, in decreasing order, by AISI 347, AISI 410, Fe-base Ti-hardened alloy, and Ni-base Ti-hardened alloy.

(*b*) Alloys 4 and 6 produced the best overall wetting of the base metals, followed, in order of decreasing effectiveness, by Alloy 2, Alloy 1, Alloy 3 and Alloy 5.

(*c*) A vacuum of 0·05–0·07 micron produced the best environmental condition for wetting. Dry hydrogen and dry helium were, respectively, less effective.

'(2) The titanium present in the iron- and nickel-base alloys reacted with hydrogen, oxygen or carbon in the protective media, to form a surface compound film which retarded wettability.

'(3) Considerable diffusion and base-metal alloying were observed when using brazing alloys 1, 2 and 6. This was partially attributed to the ability of the boron, contained in these alloys, to penetrate intragranularly into the base metals.'

'*Wetting Reactions at Superheat Brazing Temperature*

'(1) Superheating different types of high-temperature brazing alloys generally produced a decrease in the wettability of various types of high-temperature alloys, both in vacuum and in dry-hydrogen environments.

'(2) Decreased wettability was probably caused by an increase in liquid brazing-alloy/solid base-metal interfacial tension at super-heat brazing temperature.

'(3) Increased interfacial tension reflected greater diffusivity and reactivity by elements in the brazing alloy with the base metal at the superheat brazing temperature.

'(4) Wetting indexes obtained at superheat brazing temperature paralleled those obtained at a normal

brazing temperature, but at a lower order of magnitude:

(*a*) Brazing alloy 6 produced the best overall wetting of the base metals tested.

(*b*) The cobalt-base alloy was most readily wetted by the brazing alloys tested, while the iron-base Ti-hardened alloy was the most difficult base metal to wet.

(*c*) At superheat-brazing temperatures wettability results obtained in vacuum were superior to those obtained in dry hydrogen.'

Filler Wire for Welding Dissimilar Materials

SOC. AUTOMOTIVE ENGINEERS: 'Alloy Wire, Corrosion- and Heat-Resistant.'

S.A.E./A.M.S. 5675, issued Jan. 15, 1959.

Material intended primarily for use as filler metal for inert-gas arc welding of dissimilar materials is of the following composition: carbon 0·10 max., silicon 0·35 max., manganese 2·0–2·75, sulphur 0·015 max., chromium 14·0–17·0, nickel + cobalt 67·0 min., cobalt, if determined, 1·0 max., titanium 2·5–3·5, iron 10·0 max., copper 0·50 max., per cent.

Welding of Copper to Stainless Steel

H. B. BOTT: 'How to Weld Copper to Stainless Steel and Mild Steel.'

Welding Jnl., 1959, vol. 38, Mar., pp. 236–8.

The procedure described has been successfully used to weld stainless steel to copper in applications, for example, in nuclear energy plant, where the strength and corrosion-resistance of the steel is needed in combination with the electrical conductivity of the copper.

In the article full particulars are given of the procedure as applied in welding copper and 18–8-type stainless-steel specimens $\frac{3}{8}$ in. (9 mm.) thick and 12 in. (30 cm.) wide. In broad outline, the procedure involves bevelling the edges to be joined, to give an included angle of 80°, pre-heating the copper to 900°–1000°F. (480°–540°C.) and overlaying its bevelled edge with four overlapping nickel stringer beads, so producing two layers of overlay weld metal, the copper dilution in the outer layer being sufficiently low to obviate embrittlement in the final welding operation. (To avoid contact between the copper and the steel during joining, the overlay is extended well beyond each edge of the bevel.) The nickel overlay is cleaned and the 40° bevel is restored by grinding: the two components are then clamped against a copper backing bar, spaced about $\frac{1}{8}$ in. (3 mm.) apart at the root of the bevel. The ends of the joint are tack welded, and finally a complete root pass is made. After each pass the weld bead is cleaned. The beads are deposited, in a regular pattern, on alternate sides and in the middle of the joint, until the weld is complete. The same procedure may be employed to join mild steel to copper.

Each stage is illustrated and photographs of welded specimens, before and after testing, are included in the article.

The results are equally satisfactory using metal-arc gas-shielded tungsten-arc or gas-shielded metal-arc techniques: for metal-arc welding use is made of a covered nickel electrode (*A.W.S.* A5.11-54*T*, Class *E*4*N*11) and for inert-gas-shielded welding nickel wire and rod (*A.W.S.* 5.14-56*T*, Class *ERN*61) are employed.

Welding of Niobium-Stabilized Chromium-Nickel Stainless-Steel Piping and Tubing

G. E. LINNERT: 'Welding Type 347 Stainless-Steel Piping and Tubing.'

Welding Research Council, Bull. No. 43, Oct. 1958; 103 pp.

The report, which was prepared under the aegis of the Welding Research Council, comprises a review of the information available on the welding of piping and tubing in 18–8–Nb stainless steel (A.I.S.I. Type 347). The review is intended more for the engineer called upon to weld Type 347 steel than for the person interested in comparing the welding characteristics of Type 347 with those of equivalent steels with the aim of selecting the most suitable material for a specific application. The report is based on a *bibliography* of 204 items, which range in date of publication from 'prior to 1947' to 1958. The scope of the individual sections of the survey is indicated below.

Introduction

History of the development and commercial introduction of stabilized stainless steels. Discussion of current uses of Type 347 steel piping and tubing.

18–8–*Nb Piping and Tubing*

Notes on forms of tubing available; the distinction between piping and tubing; compositional variations in Type 347 steel; significance of microstructure in welding (with discussion of delta ferrite, sigma phase and carbide precipitation); mechanical and physical properties.

18–8–*Nb Weld Metal*

Historical review of the factors involved in the final development of satisfactory weld deposits in Type 347 steel. Notes on control of chemical composition in the weld; microstructure and mechanical properties of the weld metal; special grades of filler metal.

Processes and Procedures for Welding 18–8–*Nb Tubing*

The emphasis is on assessment of the suitability of the various techniques in relation to welding tubing in this type of steel. The following processes are discussed; shielded metal-arc welding, inert-gas metal-arc welding, inert-gas tungsten-arc welding, atomic-hydrogen arc welding, oxy-acetylene gas welding, pressure welding, resistance welding. Joint design and preparation, root-bead techniques,

welding procedures and techniques, post-weld heat-treatment, and post-weld finishing treatment form the remaining subjects of the section.

Properties of Welded Joints in 18-8-*Nb Tubing*

The information and data relate to mechanical properties (at room, elevated and sub-zero temperatures), corrosion-resistance, and inspection methods.

Defects in Welded 18-8-*Nb Tubing*

The following types of defect are considered: weld-metal unsoundness, weld-metal cracking, base-metal cracking, fusion-line cracking, and cracking resulting from contamination.

Performance of Welded Tubing in Service

The performance of 18-8-Nb welded tubing is assessed in relation to service under corrosive, high-temperature and low-temperature conditions.

Welding of 'Inconel' for Use in Nuclear Power Plant

W. A. FRAGETTA and G. R. PEASE: 'The Welding of 'Inconel' for Nuclear-Power Applications.'

Welding Jnl., 1959, vol. 38, Apr., pp. 347-56.

It has become generally accepted that weldments used in nuclear-power reactor systems must meet more rigid quality specifications than are laid down in most current codes. Demonstration that welded assemblies can be produced to these higher standards has therefore become essential in securing acceptance of materials employed in such plant. 'Inconel' (nickel-chromium-iron-base alloy), which has for many years been well known in high-temperature engineering, has recently developed added interest for use in construction of certain nuclear-power-plant components, particularly in systems of the pressurized-water reactor type, and the investigation reported in this paper was carried out to study the suitability of this material, from the specific aspect of its welding characteristics. Development of welding procedures which could give complete satisfaction in these applications was a major item in the research programme.

Since the use of 'Inconel' in pressurized-water systems is likely to be primarily in the form of heat-exchanger tubing and tube-sheet overlays, the main emphasis in the research was on production of three types of weldment used in heat-exchanger construction: (1) overlaying of carbon-steel tube sheets with 'Inconel'-type weld metal; (2) welding heavy-section transition butt welds between 'Inconel' and steels overlaid with steel of Type 308 (chromium 19-21, nickel 10-12, carbon 0·08 max., per cent.); (3) demonstration of soundness and reproducibility in 'Inconel' tube / 'Inconel' - overlaid tube - sheet joints. (All these types of construction are diagrammatically illustrated in the original.) The aim was development of a welding method and one welding-wire composition for each of the three types of weld.

Information already available in the laboratory of The International Nickel Company, with which the authors are associated, indicated that the desired weld quality could be obtained by use of a titanium-manganese-modified 'Inconel' composition developed in the Company's laboratory for use in the inert-gas-shielded welding process. The wire conforms to S.A.E./A.M.S. Specification 5675: *see* abstract on p. 203. Typical compositions within that range, as used in the experiments reported, are shown in the paper. The techniques used, and the results of each section of the work, are described at length, with informative illustrations and extensive test data.

The information recorded demonstrates that:

The new welding wire, deposited by the inert-gas-shielded consumable-electrode process, is capable of producing high-quality overlays on steel, as well as transition welds between 'Inconel' and stainless steel.

Metallurgically sound tube / tube - sheet welds can be obtained by the inert-gas-shielded tungsten-arc method.

The submerged-arc process is not, at present, suitable for overlaying with 'Inconel' filler wire.

To secure and maintain high levels of ductility in the overlay deposits, the temperature of the post-welding heat-treatment should be below 1200°F. (650°C.).

Control of iron dilution, which is an important factor with regard to quality of overlay deposits, is closely associated with the welding current employed and with the type of equipment used.

Corrosion-Resistance of Stainless-Steel Welds made under Carbon-Dioxide or Argon/Oxygen Protection

B. E. HOPKINSON and D. W. McDOWELL: 'Corrosion of Stainless-Steel Welds formed with Carbon-Dioxide Shielding.'

Welding Jnl., 1959, vol. 38, Apr., pp. 188s-93s.

The use of carbon dioxide as a shielding gas in consumable-arc welding of stainless steels has been retarded by the possibility of carbon pick-up from the gas, followed by precipitation of chromium carbide and sensitization of the weld metal. Some work has been reported (from U.S.A. and from the U.S.S.R.) on the use of this technique, but the investigations have been concerned only with changes in the composition of the weld metal resulting from the use of CO_2, and have not dealt with the corrosion-resisting characteristics of the joints. The present paper compares both the weld-metal composition and the corrosion-resistance of stainless-steel welded joints made (*a*) under carbon-dioxide shielding, and (*b*) under a shielding gas consisting of argon + one per cent. oxygen. Both single- and multi-pass welds were examined, the aim in the latter case being to determine whether the metal of the initial passes is sensitized by the heating involved in production of the later deposits.

The corrosion-resistance of the weld metal was evaluated by the boiling 65 per cent. nitric-acid and the ferric-sulphate/sulphuric-acid tests, and

the weld metal was analysed. In addition, a transverse section across all the passes from each specimen was prepared for microexamination, and in the case of the welds made under carbon dioxide a section showing the interface between the weld metal in the area of passes three or four, and the base metal, was also examined. Single-pass welds were made on ¼-in. (6-mm.) plate of 18-8 steels Types 304 and 304L, by the consumable-electrode arc technique, using Type 308 and 308L (20-10 Cr-Ni) electrodes. In the multi-pass welds also consumable-electrode arc technique was employed: double-vee butt-joint welds were made on Type 347 (18-8-Nb) 1-in. (25-mm.) plate. The carbon-dioxide-shielded deposits were laid down from Type 312, 308, 308L, 310 and 347 electrodes, and similar welds were made with Type 347 and 308L electrodes using oxygen-containing argon as shielding medium. A joint made with a Type 310 (25-20 Cr-Ni) electrode, using that gas mixture, was unsatisfactory, due to cracking. Full details are given of compositions of welding electrodes, and welding conditions.

The experimental results, full details of which are recorded, include determination of carbon pick-up, and of loss of silicon and manganese, and discussion of consequent constitutional changes in the weld metal. The all-over conclusion reached is that although there is some pick-up of carbon when welding is done under carbon dioxide, that gas may be used in welding stainless steels of the types examined, without impairment of corrosion-resistance. If, however, multi-pass welds are made, some sensitization of the earlier passes (as assessed by the two tests used) can occur. In practice this possible risk would have to be balanced against the advantages of the alternative gas.

Testing of Hot-Cracking Susceptibility of Welds

F. C. HULL: 'Cast-Pin Tear Test for Susceptibility to Hot Cracking.'

Welding Jnl., 1959, vol. 38, Apr., pp. 176s-81s.

Attempts to predict susceptibility to, or immunity from, hot cracking of welds on the basis of weld composition have met with little success, but many types of laboratory test have been developed in an effort to predict behaviour during welding. The author gives reference to descriptions of the most important of such tests: the Lehigh restraint test, various tests using circular-groove specimens, the Murex test and the finger test proposed by Apblett and Pellini. All the methods suggested to date have the disadvantage of being relatively slow, and of requiring a considerable amount of material and processing. Some of them are subject also to variables associated with hand welding.

This paper describes a simpler form of test, which is claimed to be free from the disadvantages mentioned above and to give more consistent results. Samples weighing 19 g. are levitation-melted in an inert atmosphere and cast in the shape of tapered pins, in a series of copper moulds. Restraints at the ends of the pin impose tensile stresses on the sample as the mould expands and as the casting solidifies and contracts. The geometry of the mould which will produce a certain extent of hot cracking serves as a means of classifying alloys in order of welding merit. The test is quick and inexpensive, and is applicable to both the evaluation of new materials and to study of the effects of alloying additions and impurities on hot cracking. Because casting a pin under conditions of restraint led to hot tearing, the procedure has been named the Cast-Pin Tear (C.P.T.) test. Its use is exemplified by reference to tests of crack-susceptibility of austenitic welds.

ANALYSIS

Colorimetric Determination of Nickel

See p. 172.

Determination of Nickel in Gold-Nickel Alloys

See p. 172.

Removal of Zinc from Ammoniacal Nickel Solution

See p. 172.

Determination of Sulphur in Nickel Electrodeposits

See p. 177.

Determination of Nickel, Zinc and Aluminium in Bronze

See p. 180.

Determination of Nickel and Other Elements in Ferrites

See p. 182.

Determination of Titanium, Zirconium, Niobium and Tantalum in Steels

See p. 185.

Identification of Corrosion Products on Copper Alloys

See p. 195.

Corrigendum

Nickel Bulletin, 1959, vol. 32, No. 3, p. 71.

A. E. PICKLES: 'Bright Annealing.'

For Metal Treatment, 1958, vol. 26, Jan., pp. 7-14.

read Metal Treatment, 1959, vol. 26, Jan., pp. 7-14.

Attention is drawn to the fact that many of the names of materials mentioned in The Nickel Bulletin are *Registered Trade Marks.*